SENSORY DIFFERENCES BETWEEN BEET AND CANE SUGARS

BY

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THESIS

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Abstract

Sucrose, commonly referred to as sugar, is a worldwide commodity used in a wide variety of food applications. Beet and cane sugars, the primary sources of sucrose, have a nearly identical chemical composition (>99%), though some differences in their analytically determined volatile profiles, thermal behavior, and minor chemical compositions have been noted. However, the sensory differences between beet and cane sugars are not well defined or documented in the literature.

The objectives of this research were to: 1) determine whether a sensory difference was perceivable between beet and cane sugar sources in regard to their aroma-only, taste and aroma without nose clips, and taste-only with nose clips, 2) characterize the difference between the sugar sources using descriptive analysis, 3) determine whether panelists could identify a sensory difference between beet and cane sugars and product matrices made with beet and cane sugars using the R-index by ranking method**,** and 4) relate the impact of information labels that specified the sugar source in an orange flavored drink to overall liking of that drink.

Data from this research indicated that panelists could discern a sensory difference between beet and cane sugars, specifically in terms of their aromas. The differences are attributed to the aroma profiles, which were characterized using descriptive analysis. The sensory profile of beet sugars was characterized by off-aromas, including off-dairy, oxidized, earthy, and barnyard aromas and by a burnt sugar aroma-by-mouth and aftertaste, while cane sugar was associated with sweet and fruity attributes.

R-index by ranking found that panelists could perceive a difference between beet and cane sugars when incorporated into some products. Masking due to the flavor and complexity of the product matrix, the quantity of sugar in the products, and variation due to processing may be influential factors in their ability to differentiate between the sugar sources when used in a product.

Results from a five-phase consumer study indicated that providing consumers with information regarding the sugar source used in orange flavored drink products has no influence on their liking of the product, though the liking scores of the sugars themselves were

significantly influenced by information conditions (blind and informed). Although the presence of information about sugar source in a product is not influential to the general public, it may have shown an effect if consumers who favor one type of sugar source were targeted for this study.

This research is significant because it documents the sensory differences between beet and cane sugars, something that is not yet defined in the literature. The studies recognized the sensory modalities in which beet and cane sugars can be differentiated and characterized their sensory profile to explain these differences. The results can also be used to make suggestions to food manufacturers as to which factors should be considered when formulating foods with beet or cane sugar sources.

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Chapter 1: Introduction

1.1 Rationale and significance

Sucrose, commonly referred to sugar, is an important commodity worldwide due to the assortment of functionalities that it provides as a food ingredient. Sugar beet and sugar cane are the primary plant sources resourced for the production of sugar (Desai and Salunkhe 1991). Refined beet sugar and refined cane sugar are both composed of greater than 99% sucrose (Potter and Mansel 1992; Colonna and others 2000; Asadi 2005).

Though the composition of beet and cane sugars are nearly identical, some chemical and thermal differences have been noted in the literature. For example, beet and cane sugars differ in their carbon isotope ratio (C_{13} to C_{12}), which is indicative of the differences in the photosynthetic pathways utilized by the plants. The carbon isotope ratio in beet is about 25%, while the ratio for cane sugar is 11% (Bubník and others 1995). Raffinose and theanderose are two other differential indicators between beet and cane sugars. Though raffinose is present in both sugar sources, it exists at a higher quantity in beet sugar (Morel du Boil 1997; Eggleston 2004). Theanderose is present in cane sugar and is believed to be a natural constituent of sugar cane (Morel du Boil 1996). Both raffinose and theanderose affect the sugar crystal growth and morphology (Liang and others 1989; Morel du Boil 1992). Using analytical flavor chemistry techniques, an off-aroma has been identified in beet sugar, which distinguishes is from cane sugar. A combination of geosmin and volatile fatty acids have been identified as the compounds responsible for this off-aroma (Marsili and others 1994; Godshall and others 1995; Moore and others 2004). Differences between beet and cane sugars in terms of their thermal behavior have also been explored. The differential scanning calorimetry (DSC) thermograms exhibit one large endothermic peak for beet sugar and two for cane sugar, one small endothermic peak and one large endothermic peak (Lu and others 2013).

The exploration of differences between beet and cane sugars extends beyond the scientific world. It has been a topic of conversation in many popular press sources including online articles, blogs, and forums (Ridge 2001). The discussions have focused on differences in beet and cane sugars as well as their performance in products. While some users deem beet and cane sugars as being identical, others argue that there are noticeable differences between them (Morgan 1999; DeSantis 2007).

To date, little published research is available on the sensory differences between beet and cane sugars alone and in products (Monte and Maga 1982). Therefore, this research is significant because it explores the differences between beet and cane sugars from a sensory perspective. The findings from this research also offer insight for the development and marketing of sugar containing food products. It suggests that additional factors, besides market price, be taken into consideration when selecting the sugar source in a product formulation.

1.2 Project Objectives

The objectives of this research were to: 1) determine whether a sensory difference was perceivable between beet and cane sugar sources in regard to their aroma-only, taste and aroma without nose clips, and taste-only with nose clips, 2) characterize the difference between the sugar sources using descriptive analysis, 3) determine whether panelists could identify a sensory difference between beet and cane sugars and product matrices made with beet and cane sugars using the R-index by ranking method**,** and 4) relate the impact of information labels that specified the sugar source in an orange flavored drink to overall liking of that drink.

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Chapter 2: Literature Review

2.1 Sucrose

Sucrose, commonly referred to as sugar, is a worldwide commodity known for its characteristic sweet taste and versatility with regard to product functionality. It is a common household ingredient and is frequently used in manufactured food products. Sugar also has uses in the pharmaceutical industry.

Chemical Properties of Sucrose

Sucrose is a simple carbohydrate with the molecular formula $C_{12}H_{22}O_{11}$ and a scientific name α-D-glucopyranosyl-β-D-fructofuranoside. It is a disaccharide composed of D-glucose and D-fructose linked by an α-1, 2 glycosidic linkage (Fischer 1891; Colonna and others 2000). Due to the absence of a free anomeric carbon, sucrose is a non-reducing sugar and therefore cannot undergo mutarotation (Colonna and others 2000).

Sources of Sucrose

Sucrose can be obtained from a variety of plant sources including sugar palm, sweet sorghum and maple tree, though a majority of commercially produced sucrose is from sugar beet (*Beta vulgaris*) and sugar cane (*Saccharum officinarum*) (Desai and Salunkhe 1991).

Cane sugar accounts for 80% of the global supply and the remaining 20% is from beet sugar (Fairtrade and Sugar 2013). Though sugar is produced worldwide, the United States is one of the world's largest producers. The 2013/14 share of production forecast in the United States is 57.2% for beet sugar and 42.8% for cane sugar (SMD and USDA 2014).

Sucrose is a product of photosynthesis. The plant utilizes energy from the sun to convert carbon dioxide and water into sugar and oxygen. The resulting sucrose is stored in the leaves and stalks of sugar cane and in the roots of sugar beets (Colonna and others 2000).

Function of Sucrose in Food Industry Applications

Sugar is a versatile ingredient that is used as a condiment, decorative material, preservative, sweetener, foodstuff, and in medical applications (Colonna and others 2000). Besides its obvious role of imparting sweetness, sugar is used to confer other important functions in food applications.

Caramelization is a browning reaction that takes place when sucrose (or other simple sugar, such as glucose or fructose) is heated at a specific temperature for a length of time (Lee and others 2011; Schmidt 2012). Flavor development and surface browning occur in various products due to caramelization (Davis 1995). Desirable flavors such as caramel, as well as Undesirable flavors such as burnt, bitter, and acrid may result from caramleization of sugar (Monte and Maga 1982). Caramelization takes place in a number of food products including confections, meats, and breads (Davis 1995).

Though sucrose itself cannot take part in the Maillard reaction, sucrose may participate once it has been hydrolyzed to form glucose and fructose. Glucose and fructose are reducing sugars and therefore react with amino acids to produce browning and flavor compounds (Karel and Labuza 1967).

The gelatinization process is affected by sugar as well. By competing with starch for available water, sugar delays the onset of gelatinization (Hester and others 1956). The delay in gelatinization occurs because sugar decreases the water activity of the solution and interacts with the amorphous regions of the starch granule to stabilize it (Spies and Hoseney 1982).

Sugar also serves a role in dough and batters by incorporating air into fat during mixing. By doing so, the sugar can aid in achieving a light texture in the product (Paton and others 1981; Wilderjans and others 2013).

The influence of sugar on foam stability is important as well. Sugar works as a whipping aid to stabilize beaten foams by interacting with protein (Lomakina and Mikova 2006; Foegeding and others 2006; Raikos and others 2007). The addition of sugar increases foam stability and lengthens the drainage time (Berry and others 2009).

Sugar is also effective in delaying gluten development by competing with gluten-forming proteins for water. This inhibits the proteins from fully hydrating and results in a less rigid dough (Pareyt and others 2009). The texture and viscosity of many foods is dependent on sucrose. The physical and chemical functions of sugar vary in different applications.

Flavor of Sucrose

Sugar is associated with sweetness. Sucrose is the gold standard for sweetness and therefore used as a reference when evaluating the sweetness of other sugars or sweeteners (Davis 1995). The perception of sweet taste occurs by activating taste cells on the tongue and soft palate, which contain sweet receptors. The sweet compound binds to and activates the receptors, a dimeric G-protein coupled receptor made up of T1R2 and T1R3 subunits. Activation causes the release of neurotransmitters and transmission of taste information to the brain and hence, the perception of sweet taste (Nelson and others 2001; Li and others 2002).

The taste and aroma of sugar should be clean and pure with no taints or off notes (Godshall 1998). Any sensory characteristic aside from sweetness is considered to be an off-flavor (Godshall 1996). Pure sucrose, regardless of its source, should have an identical sensory profile. Though sugar manufacturers strive to produce pure sucrose, the quality of refined sugar is dependent on the processing protocol and source of sugar used. Often, refined sugar has an aroma that is indicative of its source. These aromas are present at extremely low concentrations, but they are often detectable by humans due to the sensitivity of the human nose (Godshall 1998).

2.2 Sugar Beet (*Beta vulgaris* L.)

Agricultural Practices

The sugar beet is a biennial root crop that can grow in a wide range of climatic conditions. Frost is a threat to the plant because it terminates the photosynthetic production of sucrose. Therefore, sugar beets are harvested around the time of the first frost (Asadi 2007).

Sugar beet plants grow a large leaf canopy, which aids with photosynthesis. The amount of leaf growth is an indication of crop health. As harvest nears, the plant terminates leaf growth and focuses on sucrose production by converting sunlight and nutrients to sugar. The leaves turn yellow during this stage signifying the shift from leaf structure growth to sugar production (Pfenninger 2012).

Beets are harvested in the fall, once they have reached maturity. A machine defoliates the plant and lifts the beets from the ground. The sugar beets are then transferred to a holding bin and transported to a receiving station. Once at the receiving station, the beets travel down a series of rollers, which separate any dirt or residual material from the beets. After, the beets are put into long-term storage piles and may be stored there for as long as seven months before processing, depending on demand. During prolonged storage, some of the sugar in the root is consumed via natural respiration. This will reduce the commercial value of the sugar beet and can lead to yeast and mold infections. Proper storage conditions and air ventilation can be effective in slowing decay (Pfenninger 2012).

Processing of Sugar Beets to Refined White Sugar

Though the processing protocol of beet sugar can vary, Figure 2.1 illustrates the typical unit operations in the manufacturing of beet sugar. Sugar beets are transported from storage to the processing facility where they are immediately placed into a cement trough of moving water to remove any remaining stones and dirt before entering the factory. The clean beets are transferred to a rotating slicer that cuts the root into V-shaped slices called cossettes (Godshall 2007).

The cossettes are heated and then travel through a diffuser with water flowing opposite of them. The temperature in the diffuser is around 70^{o}C and residence time in the diffuser is typically between 45 to 60 minutes (Asadi 2007; Godshall 2007). This process denatures the beet cell wall, opening the cell membranes and extracting the sucrose. Wet cossette pulp, the solid residual material remaining after diffusing, is pressed to recover any remaining sucrose and then dried for animal feed. After the diffusing and pressing process, a cloudy, unstable solution results called raw juice (Asadi 2007; Godshall 2007).

Raw juice is purified by heating and combining it with carbon dioxide and lime (carbonation). Lime acts as a clarification-filtration medium by forming a precipitate with non-sucrose components. Remaining calcium from the lime is removed by forming calcium carbonate with the added carbon dioxide. This serves as the primary clarification agent. Sulfitation, the process of treating juice with approximately 150 ppm sulfur dioxide gas, often follows carbonation. Sulfitation aids in inhibiting color formation reactions. The juice purification steps are implemented to terminate microbial activity, clarify the juice, and ensure that the juice is chemically stable. The purified juice is called thin juice (Asadi 2007; Godshall 2007).

Once the impurities are removed, the thin juice is concentrated in a multiple step evaporation system to yield thick juice. Thick juice contains 50-65% solids (Godshall 2007). Next, crystallization takes place consisting of a multiple step boiling process. Thick juice is combined with low grade sugar to produce standard mother liquor. The juice is boiled under vacuum in a vacuum pan to further concentrate the solution. Fine sugar crystals (i.e. sugar seed) are then added to the pan to initiate crystal growth. Once the crystals reach their desired size, they are fed into a centrifuge where the remaining mother liquor is spun off. This boiling scheme is often repeated three times. A rotating drum granulator-cooler reduces the moisture of the crystal to about 0.03% by passing warm air over the crystals. For optimum results, the sugar should cure for 24 hours before storage or shipping. Much of the final product is stored in silos to provide continuous distribution (Asadi 2007).

Aromas in Beet Sugar

Often, off-aromas are perceived exuding from granulated beet sugar, which causes them to be rejected by consumers. Using purge and trap techniques, Marsili and others (1994) identified geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol), 2,5-dimethylpyrazine, furfural, butyric acid, and isovaleric acid as being probable contributors to the off-odor in beet sugar. To reproduce the off-odor perceived in beet sugar, odorless cane sugar was spiked with varying levels and combinations of the five suspect compounds. A mixture of geosmin and volatile organic acids yielded an aroma that was identical to that of beet sugar.

Godshall and others (1995) categorized the major components of aromas identified and detected in beet sugar. From a quantitative and qualitative perspective, volatile fatty acids including acetic, propionic, butyric, and isovaleric were found to be most significant contributors. Combinations of the volatile fatty acids are characterized by a cheesy dairy like aroma. Earthy-beety, straw, silage, mushroom-like aromas were also indicated as being important. Though these aromas were perceivable to the human nose, they resulted in little or no peak on the olfactory detection chromatogram. This may have been true for geosmin. In this study, researchers were unable to find geosmin because it is present below detection levels needed to generate chromatographic peaks. Alcohols and aldehydes were also present in the beet sugar and contributed a green or plantlike aroma. The presence of musty, nutty, and caramel aromas was described as well.

Moore and others (2004) also studied the volatile compound composition of beet sugar. Solid phase micro extraction and headspace analysis were used. The chromatograms indicated that reject sugars could be differentiated from acceptable sugars by the concentration of volatile fatty acids present in the sample. Reject sugar samples contained higher levels of volatile fatty acids than did acceptable sugar samples. Butanoic and isovaleric acids were identified as key contributors in the off-aroma of reject beet sugar samples.

Sources of Off-Aromas in Beet Sugar

There are numerous hypothesized causes for the off-aromas present in beet sugar. One such cause is soil microorganisms. It is thought that the beet root may uptake compounds or microorganisms in the soil may adhere to the root. This can result in an earthy and musty odorant in the beet sugar (Marsili and others 1994; Godshall and others 1995). Earthy aromas, such as those from geosmin, have also been found to reside as a natural component of the beet itself (Lu and others 2003).

Malodorous compounds in beet sugar may also originate from the breakdown of the tops, leaves, or the root of the beet. Oxidation of fatty acids in the beet and fermentation of plant materials cause green and mushroom aromas. Degradation worsens with extended storage of the sugar beets prior to processing (Clarke and others 1995; Godshall and others 1995).

The volatile compounds in beet sugar are found in a thin layer on the surface of the sugar crystal. During production, seeds are placed in supersaturated syrup to initiate crystal growth. Once the sugar crystals reach their desired size, a centrifuge separates them from the remaining syrup. Often times, a thin layer of syrup remains on the surface of the sugar crystal even after centrifugation. Most of the plant and process derived aromas are contained within this outer layer (Clarke and others 1995; Godshall and others 1995; Colonna and others 1996)

Aeration and ventilation of sugar during storage was suggested to result in partial elimination of the off-aromas in beet sugar (Clarke and others 1995; Colonna and others 1996; Duffaut and others 2004). The use of ozone versus air treatment was studied by Duffaut and others (2004) as potential solutions to malodor removal in beet sugar. Data indicated that air was superior because it was more effective and economical. Treatment suggestions such as additional washing in the centrifuge and ensuring quality air in the dyers have also been proposed to aid in off-aroma removal (Clarke and others 1995; Colonna and others 1996; Duffaut and others 2004). Lowering the pH has been shown to suppress off-aromas in beet sugar (Godshall 1988).

2.3 Sugar Cane (*Saccharum officinarum* L.)

Agricultural Practices

Sugar cane is a perennial crop that grows primarily in tropical and subtropical regions. The cane stalk is round and jointed. A hard rind and waxy film surround it. A leaf grows at each node on the stalk. As the stalk grows taller, the leaves on the lower part of the stalk die and fall off (Godshall 2007).

Sugar cane is typically harvested during the cooler, drier seasons. Burning cane fields is a practice done prior to harvesting in order to remove leaves and tops. This increases harvesting efficiency and the sugar yield per ton of sugar cane (Asadi 2005). Though it has many benefits, the practice of burning is becoming less common due to environmental and social concerns. Sugar cane can be harvested by hand, though today it is most commonly machine harvested. Whole-stalk harvesters or chopper harvesters are typically used for machine harvesting. Whole-stalk harvesters maintain the stalk integrity, allowing it to be stored before being processed. Chopper harvesters cut the stalk into 8 to 12 inch pieces, called billets, and require immediate processing due to faster juice quality deterioration. The sugar cane is transported to the mill after harvesting where it is immediately washed to remove any debris (Godshall 2007).

Processing of Sugar Cane to Sugar

Figure 2.2 is a flowchart of the typical unit operations involved in the manufacturing of cane sugar. The cane stalks are prepared for milling by being chopped into smaller pieces via a shredder. Shredded sugar cane travels to the milling tandem where the juice is extracted as the cane fibers are compressed. To enhance the extraction of the juice, juice from previous mills is added to the cane fiber. This process is called imbibition. Diffusion is an alternative to milling. When utilizing diffusion, the cane must be shredded finer compared to the milling process. For this reason, diffusion typically results in a higher extraction yield. The finely shredded cane enters a diffuser, where it moves countercurrent to hot water. The sucrose exits the ruptured cells of the cane fiber as it travels through the diffuser (RW.ERROR - Unable to find reference:99; Godshall 2007).

Once the juice is extracted, it is heated and combined with lime as part of the juice purification process. The heat acts to disinfect the juice and aids in the precipitation of the impurities. The lime raises the pH to minimize inversion. A flocculent precipitate, called muds, results from the addition of heat and lime. Muds settle out of the juice in the clarifier and are then processed in a rotary vacuum filter to recover any sucrose. Clarified juice enters a multiple-effect evaporator to concentrate the sugar solution. The resultant evaporator syrup enters a vacuum pan to concentrate the syrup to supersaturation in order to initiate sugar crystallization. Fine sugar crystals are added as seed to the pan to help initiate crystal growth. The residual liquor is recycled multiple times to ensure maximum sucrose extraction. A high speed centrifugal machine separates crystals from the syrup. As the sugar spins, the syrup is drawn to the outside and crystals are gathered in the inside. After separation, the raw crystals are dried and moved to storage. At this point in the processing, the crystals contain about 98.0 to 98.5% sucrose (Godshall 2007).

Refining involves processing the raw sugar to white sugar. Upon arrival to the refinery, sugar undergoes a process known as affination. Raw sugar is combined with saturated syrup to soften the film of molasses on the surface of the crystals. A centrifuge separates the crystals from the syrup and washes the crystals to remove any residual syrup. The washed crystals are then dissolved in hot water and the resulting solution is purified. Purification involves a clarification and a decolorization step. Clarification is achieved by adding lime to the liquor in order to remove impurities. The most common clarification techniques are carbonation and phosphatation. Clarification is followed by decolorization in which the liquor is treated with bone char, granular activated carbon, ion-exchange resins, or a combination of these methods. Decolorization yields a clear, lightly colored liquor. This liquor is concentrated in a multiple-effect evaporator and then crystallized using a series of vacuum pans, the same method used to produce the raw sugar. Crystals are separated from the liquor in a centrifuge and washed with hot water. Hot air is blown through a rotating drum to dry the crystals. The temperature of the sugar when exiting the dyer is between 52 and 55^{o}C. The sugar is cooled to about 45^{o}C before being put in silos for conditioning. The moisture content of the sugar is further reduced during conditioning. A current of air passes through a silo of sugar for an extended period of time in order to yield of moisture content of 0.025% or less. Conditioning typically takes from 24 to 72 hours. The final product is packaged and sent to the warehouse or stored in silos in bulk and packaged as needed (RW.ERROR - Unable to find reference:99; Godshall 2007).

Aromas in Cane Sugar

Generally, cane sugar is perceived as having a “sweet” and slightly caramel aroma (Godshall 1998). The presence of undesirable aromas is significantly less prevalent in cane sugar than in beet sugar. Off-aromas may arise from compounds found in the sugarcane juice that are retained through the refining process. Organic acids such as malic acid, aconitic acid, succinic acid, and fumaric acid may be responsible for an acid taste in cane sugar. A bitter and astringent flavor can be caused by p-Hydroxybenzoic acid, syringic acid, and p-Hydroxycinnamic acid. Acetaldehyde, a fresh, fruity, green volatile compound, is occasionally identified in the sugar as well. Additionally dimethylsulfide, 3-hexen-1-ol, and 1-hexen-3-ol, volatile compounds found in the leaves of sugar cane, can contribute a green aroma (Godshall 1996).

Sources of Off-Aromas in Cane Sugar

Off-aromas present in cane sugar can often be traced back to compounds in the sugar cane juice that remain throughout processing. Cane leaves, acid degradation of sucrose, microbial activity, and packaging are possible contributors to undesirable aromas in cane sugar as well (Godshall 1996).

2.4 Differences between beet and cane sugars

Beet and cane sugars are nearly chemically identical, with a purity usually greater than 99% (Table 2.1). Though their compositions are extremely comparable, there are some differential markers between beet and cane sugars in addition to the aroma differences discussed above.

Composition

Beet and cane sugars are primarily composed of sucrose, although they do contain impurities consisting of water and trace components from the sugar plant source (Colonna and others 2000). The Sugar Processing Research Institute (New Orleans, LA) has conducted numerous studies to examine the compositional differences between beet and cane sugars. Godshall (2013) compiled a table to compare the composition of refined beet and cane sugars, which is given in Table 2.2.

Carbon Isotope Ratio

Sugar beet and sugar cane differ in terms of their carbon fixation process. Carbon fixation is a pathway for autotrophs in which carbon dioxide is converted to organic compounds. The two main photosynthetic pathways are C_3 and C_4. Sugar beet is a C_3 plant meaning that it utilizes the *Calvin* cycles in the initial phase and forms a 3-carbon compound as the first stable intermediate. Sugar cane is an example of a C_4 plant due to its ability to fix carbon dioxide into a 4-carbon compound before entering the *Calvin* cycle. C_3 plants are typically grown in temperate zones, while C_4 plants thrive in hot regions with intense sunlight (Leblebici 2009). Isotope ratio mass spectrometry (IRMS) can be used to determine the $^{13}C/^{12}C$ ratio, which distinguishes C_3 plants from C_4 plants (Eggleston and others 2005). Beet sugar has a carbon isotope ratio of about 25%, while the ratio for cane sugar is 11% (Bubník and others 1995).

Processing

One major difference between beet and cane sugar processing is that beet sugar refining is typically a one step process while cane sugar requires two steps. Sugar beets can be processed directly to refined sugar. On the other hand, the production of cane sugar requires the cane to first be processed to raw sugar and then from raw to refined sugar. The two stage processing scheme is necessary for cane sugar but not for beet sugar due to the nature of the coloring material. In order for white sugar with an ICUMSA color of 25-40 to be produced, cane evaporator syrup must have a significantly lower ICUMSA color unit than beet evaporator syrup. Sugar beets have lower molecular weight colorants, lower polysaccharide content, and have colorants predominately composed of alkaline degradation products of invert sugar, which make the colorant material different from those in sugar cane (RW.ERROR - Unable to find reference:102).

Another difference between beet and cane sugar processing is the sulfitation step in beet sugar refining. This step involves the addition of approximately 150 ppm of sulfur dioxide gas to the juice. Sulfitation aids in color control, removes traces of calcium, and adjusts the pH. The use of sulfitation in cane sugar processing has been discussed, though it is rarely implemented in the United States (RW.ERROR - Unable to find reference:102).

One last difference is the use of bone char in the decolorization step in the production of cane sugar. Bone char is a commonly used decolorizing adsorbent capable of removing colorants, colloidal material, and ash components from the clarified cane liquor (RW.ERROR - Unable to find reference:102). The use of bone char in the production of cane sugar is a concern to many vegans.

Raffinose Content

Raffinose is a trisaccharide which is present in beet and cane sugars. The presence of raffinose impacts the crystal shape and growth rate, resulting in the formation of elongated crystals and crystallization inhibition (Liang and others 1989). Raffinose exists at a higher level in beet sugar compared to cane sugar (Morel du Boil 1997; Eggleston 2004). The amount of raffinose present in sugar beets varies depending on growing climate and amount of time in storage (Morel du Boil 1996).

Theanderose Content

Theanderose has been identified at discernible levels in cane sugar. Because it does not increase with deterioration, it is believed that theanderose is a natural constituent of sugar cane. Due to its absence in sugar beet, it has been recognized as a differential indicator between beet and cane sugars (Morel du Boil 1996). The presence of theanderose results in the elongation of the c-axis in the crystal (Morel du Boil 1992).

Thermal Behavior

The thermal behavior of beet and cane sugars has been investigated by Lu and others (2013). Differences were observed between the sugars in the DSC thermogram. Beet sugar samples resulted in one large endothermic peak (Figure 2.3), while two endothermic peaks were observed with cane sugar samples, one small peak and one large peak (Figure 2.4). An additional study was performed to collect visual observations of beet and cane sugars in sealed and heated ampules. Figure 2.5 illustrates the differences between beet and cane sugars when held at 160^{o}C for 180 minutes in a GC oven. Beet sugar remains granular but has a light brown color and the cane sugar is a medium brown liquid (Lu and others 2013).

2.5 Other Topics Related to Sugar

Beet Sugar versus Cane Sugar

The controversy regarding the reputation of beet and cane sugars has been a topic of discussion not only in the scientific community, but also in various media outlets and popular press sources. Scientific evidence has identified differences in aroma profiles, composition, and thermal properties of beet and cane sugars (Marsili and others 1994; Bubník and others 1995; Pihlsgard 1997; Morel du Boil 1997; Eggleston 2004; Lu and others 2013).

Differences between beet and cane sugars and their performance in products have also gained attention by consumers in online articles, forums, and blogs (Ridge 2001). Some users regard the two sugars as the same, while others disagree and argue that there is a noticeable difference between them. Harold McGee, a world-renowned authority on the chemistry of foods and cooking, shed some light on this issue in his book. He wrote, "…beet sugar sometimes carries traces of defensive chemicals called saponins… These are known to cause the development of a scum in syrups, and may also be responsible for the poor baking performance sometimes attributed to beet sugar. (This reputation may be an undeserved legacy of the early 20th century, when refining techniques weren't as effective and the quality of beet sugar often didn't measure up to that of cane sugar)" (McGee 2004). A cooking columnist and author, Marion Cunningham, offered her opinion regarding this matter in a newspaper article. Cunningham suggests that beet and cane sugars yield different results in baking depending on the recipe: "It *[the sugar source]* matters in recipes for baked goods like angel food cake. It just isn't right with beet sugar" (Morgan 1999). Ronald DeSantis, a Certified Master Chef from the Culinary Institute of America (CIA), contends otherwise. A letter from DeSantis (2007) to the United States Beet Sugar Association told of a contractual independent study that was conducted by the CIA. Objective sensory testing was used to evaluate six CIA recipes and six consumer-available retail products prepared with both beet and cane sugars. However, specifics on the methodology, sample preparation, and data analysis were not provided. Findings from the study determined that "…sugar from sugar beets was shown to perform as functionally equivalent to cane sugar, with no discernible taste difference found in products evaluated in sensory testing" (DeSantis 2007).

Many other popular press sources debate whether beet and cane sugars are perceptibly different. Quotes from participants of online blogs, forums, and articles regarding their viewpoint on this matter are summarized in Table 2.3, Table 2.4, and Table 2.5. Currently, there is little supporting scientific evidence for either viewpoint.

Health Implications of Sugar

The prevalence of obesity and related conditions and diseases has escalated worldwide. Throughout the past decade, numerous studies have been conducted to understand the underlying cause of these health concerns. The Dietary Guidelines for Americans were created in order to promote health and reduce risk of disease. As part of the guidelines, consumers are advised to limit the consumption of foods with added sugars.

Sugar has been suggested to be associated with many adverse health implications. The relationship between risk of dental caries and sugar consumption has long been understood. Cariogenic bacteria in dental plaque use sugar as a substrate to produce acid and attack the enamel surface (Finn and Glass 1975).

Research has also examined the impact of sugar consumption on hyperactive behavior. A review of correlational, intervention, and controlled challenge studies examined the scientific evidence concerning this relationship (Milich and others 1986). Data from the various studies suggest little evidence that sugar and hyperactivity are associated (Gross 1984; Behar 1984; Wolraich and others 1985).

The role of sugar in obesity, risk of heart disease, and metabolic syndrome has been studied as well. Various research methods have been used to study the relationship between sugar and these health conditions, resulting in inconsistent findings (Forshee and others 2008; Van Baak and Astrup 2009; Hu and Malik 2010). Therefore, there is insufficient evidence to validate the relationship between sugar and obesity, risk of heart disease, and metabolic syndrome.

High Fructose Corn Syrup Versus Sucrose

The debate about the metabolic difference between high fructose corn syrup and sucrose was fueled by a publication of a commentary in the American Journal of Clinical Nutrition (Bray and others 2004). The study hypothesized a direct relationship between high fructose corn syrup and obesity based on a temporal association. This hypothesis was reported as fact in various journal, magazine, newspaper, and news sources, which increased public concern about high fructose corn syrup. Research comparing health implications of pure fructose to pure glucose also added to the confusion and misunderstanding, since neither of these sugars are typically consumed in isolation in food products (Stanhope and others 2009).

The composition of high fructose corn syrup and sucrose are nearly the same. Typically, the high fructose corn syrup used in the industry contains 55% fructose and 45% glucose. Sucrose is comprised of 50% fructose and 50% glucose. Sucrose is hydrolyzed to fructose and glucose in the small intestine. Therefore, the absorption of high fructose corn syrup and sucrose is identical in the human gastrointestinal tract. Research studies have negated the idea that metabolic differences between high fructose corn syrup and sucrose exist (Anderson 2007; White and others 2010). Despite the scientific evidence, many food and beverage manufacturers have switched from high fructose corn syrup to sucrose in their product formulations in order to please consumers.

Multiple scientific studies and proceedings from symposia have determined that high fructose corn syrup consumption is not the unique cause of obesity (Melanson and others 2007; Soenen and Westerterp-Plantenga 2007; Melanson and others 2008; Stanhope and Havel 2008). The American Dietetic Association and the American Medical Association issued a statement to support these scientific findings (American Dietetic Association 2004; American Medical Association 2008).

2.6 Sensory Methodologies

Consumer Sensory Evaluation

The objective of a consumer test is to determine consumer acceptance or preference of a product based on its sensory characteristics (Jellinek 1964). These methods are important in understanding consumer food choice, which may be an indicator of product success. Various methods can be used to gauge consumer acceptance and preference towards a product (Stone and Sidel 2004).

Hedonic scaling is the most commonly used acceptance testing method. Typically, participants use a 9-point hedonic scale to evaluate a product for the degree of liking (Peryam and Girardot 1952). The scale is constructed with equal intervals and each interval is assigned with a numerical value. The numerical values aid in data analysis. The hedonic scale is widely accepted due to its ease of use and reliability (Stone and Sidel 2004; Lawless and Heymann 2010). Just-right scales, food action rating scales, appropriateness scales, and barter scales are other variations of acceptance tests (Lawless and Heymann 2010).

To compare two products and determine which product the consumers prefer, a paired preference test is used. This method requires the consumer to evaluate two samples and indicate which of the two they prefer (Resureccion 1998). Paired preference is typically a forced choice test, although it is possible to include a “no preference” response option (Gridgeman 1959; Odesky 1967). Preference ranking is another method that can be used to understand consumer liking of various products. Participants rank several products in order of preference. This method provides information on the direction of the preference among the products (Stone and Sidel 2004; Lawless and Heymann 2010).

Descriptive Analysis

Descriptive analysis is utilized to characterize the sensory attributes of a single product or comparison among several products, providing quantitative scores for qualitative descriptors (Stone and others 1974). This type of methodology is frequently used in shelf-life testing, product development, and quality assurance (Lawless and Heymann 2010). Quantitative descriptive analysis (QDA) and Spectrum are the most commonly used descriptive analysis techniques.

In QDA, 10 to 12 trained judges evaluate products by generating terms, reference standards, and verbal definitions that describe product differences. A panel leader facilitates discussion and supplies materials, but is not an active participant. During initial sessions, panelists collaborate to create a consolidated list of terms, references, and definitions. Panelist performance is evaluated by the leader relative to that of the entire panel before actual product evaluations take place. Product evaluations take place individually. Panelists use a line scale anchored with words that were generated by the panel to describe the intensity of rated attributes. Data generated from QDA can be analyzed using analysis of variance and multivariate statistical techniques (Stone and others 1974; Zook and Wessman 1977).

The Spectrum method differs from QDA because it involves the use of a standardized lexicon of terms. Another difference is the type of scale used for product evaluation. Unlike QDA, Spectrum scales are standardized and anchored with multiple reference points. A universal scale is used and therefore, data can be compared across different studies. The Spectrum method requires extensive panel training and a panel leader who takes an active role (Civille and Lawless 1986; Meilgaard and others 1999).

R-index by Rating and Ranking Tasks

The R-index is a measure of discrimination to determine the degree of difference from a conceptual standard. This measure is derived from signal detection theory (O'Mahony and others 1983; O'Mahony 1992). The theory is based on a panelist's ability to discriminate between a noise and signal (test) samples, where the noise and signal distributions are normal (Green and Swets 1966; Brown 1974; Bi and O'Mahony 1995).

Rating and ranking tasks can be used to measure R-index. In the rating method, panelists are presented with a sample and asked to determine whether the sample is a signal or noise using a sureness-rating scale. The ranking task requires panelists to rank the signal samples in terms of their similarity to the noise (Brown 1974).

Regardless of the method used, the degree of difference between the noise and each of the test samples is computed using an R-index analysis. A response matrix is constructed for each sample to summarize the data collected. The data from the matrix are converted to R-index scores using O'Mahony's method (1992).

Statistical significance of the R-index is determined by comparing the calculated value to the critical value tabulated by (Bi and O'Mahony 1995; Bi and O'Mahony 2007). If the calculated R-index measure is greater than the critical R-index measure, the null hypothesis is rejected. The R-index of the noise is 50%. Therefore, an R-index value of 50% indicates parity between the noise and signal sample, while an R-index of 100% is indicative of perfect discrimination between the noise and signal sample. R-index values that fall between 50% and 100% signify partial discrimination. The higher the probability of discrimination, the greater the degree of discrimination between the noise and signal. An R-index value below chance level probability, between 0% and 50%, signifies that the panelists identified the sample as being confusable, yet different from the noise sample (O'Mahony 1992; Lee and others 2007).

Using the R-index by rating or ranking test is advantageous compared to general difference tests. Unlike general difference tests, the R-index by rating or ranking test allows multiple comparisons to be made at once rather than comparing one pair of samples at a time. Because the degree of difference among samples can be determined in a single session, less testing sessions are needed compared to general difference tests to obtain equivalent data.

General difference tests also have a lower power and therefore, require more participants (O'Mahony 1992).

Tetrad Test

The tetrad test is a type of difference test with many practical applications. Four stimuli, two groups of two identical samples, are presented to the panelist in a tetrad test. Panelists are asked to group the samples into two groups of two samples based on similarity. The instructions of the tetrad test can be adjusted to specify the nature of the difference as well (Masuoka and others 1995; Delwiche and O'Mahony 1996).

The unspecified tetrad test is often compared to the triangle test, duo-trio test and the same-different test. Compared to these other unspecified methods, the tetrad test has higher power and thus, requires a smaller sample size (RW.ERROR - Unable to find reference:161; Masuoka and others 1995; Delwiche and O'Mahony 1996; Garcia and others 2012). Due to its higher sensitivity and power, the tetrad test has been gaining popularity.

Data obtained from the tetrad test can be analyzed by computing d’ and the variance of d’. d’ is an estimate of the measure of the degree of difference between two product. This value is determined by the proportion of correct responses from a difference test and can be obtained using tables (Ennis 1993; Ennis and others 1998). The variance of d’, the likelihood that d’ will be significantly different from zero, can be computer from tables as well (Bi and others 1997; Bi and others 2010). d’ and the variance of d’ can also be generated using IFPrograms™ software (Version 8.1: Richmond, VA).

2.7 Chapter Summary

This chapter was a review of literature pertaining to sucrose, specifically beet and cane sugars. A thorough review of beet and cane sugars in the literature revealed scientific evidence on differential indicators between the sugar sources and also helped to identify gaps in knowledge regarding the topic. Future studies on beet and cane sugar should explore the sensory characteristics of the sugars, a topic with very little published literature.

2.8 References

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Table 16--U.S. beet and cane sugar production (including Puerto Rico), by fiscal year and share of total [Internet]. National Agricultural Statistics Service and Sweetener Market Data (SMD), Farm Service Agency, USDA; 2014 [Accessed 2014 2/28]. Available from: http://www.ers.usda.gov/

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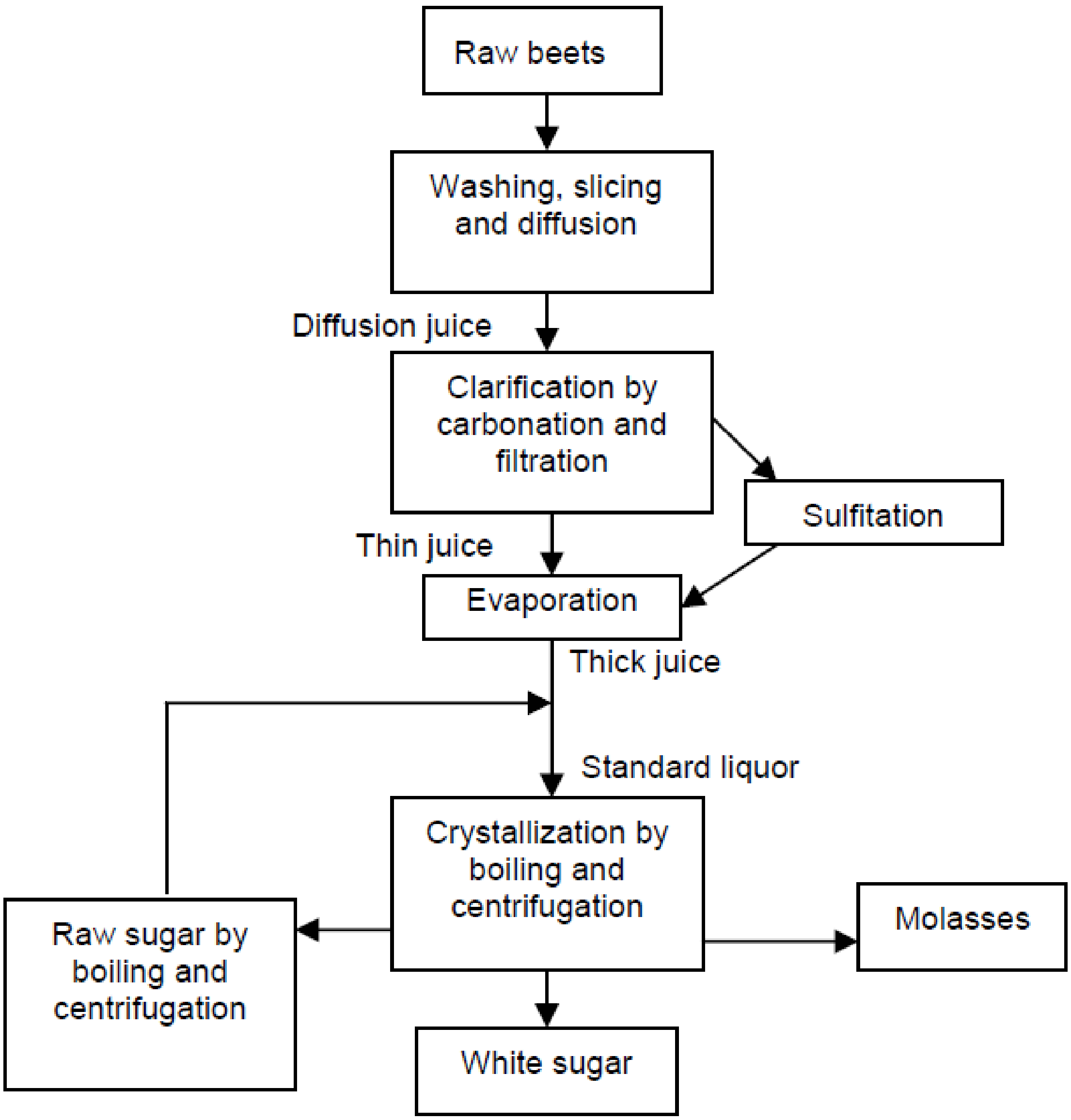


Figure 2.1 Flowchart of the typical unit operations for the processing of refined beet sugar (Clarke and others 1997).

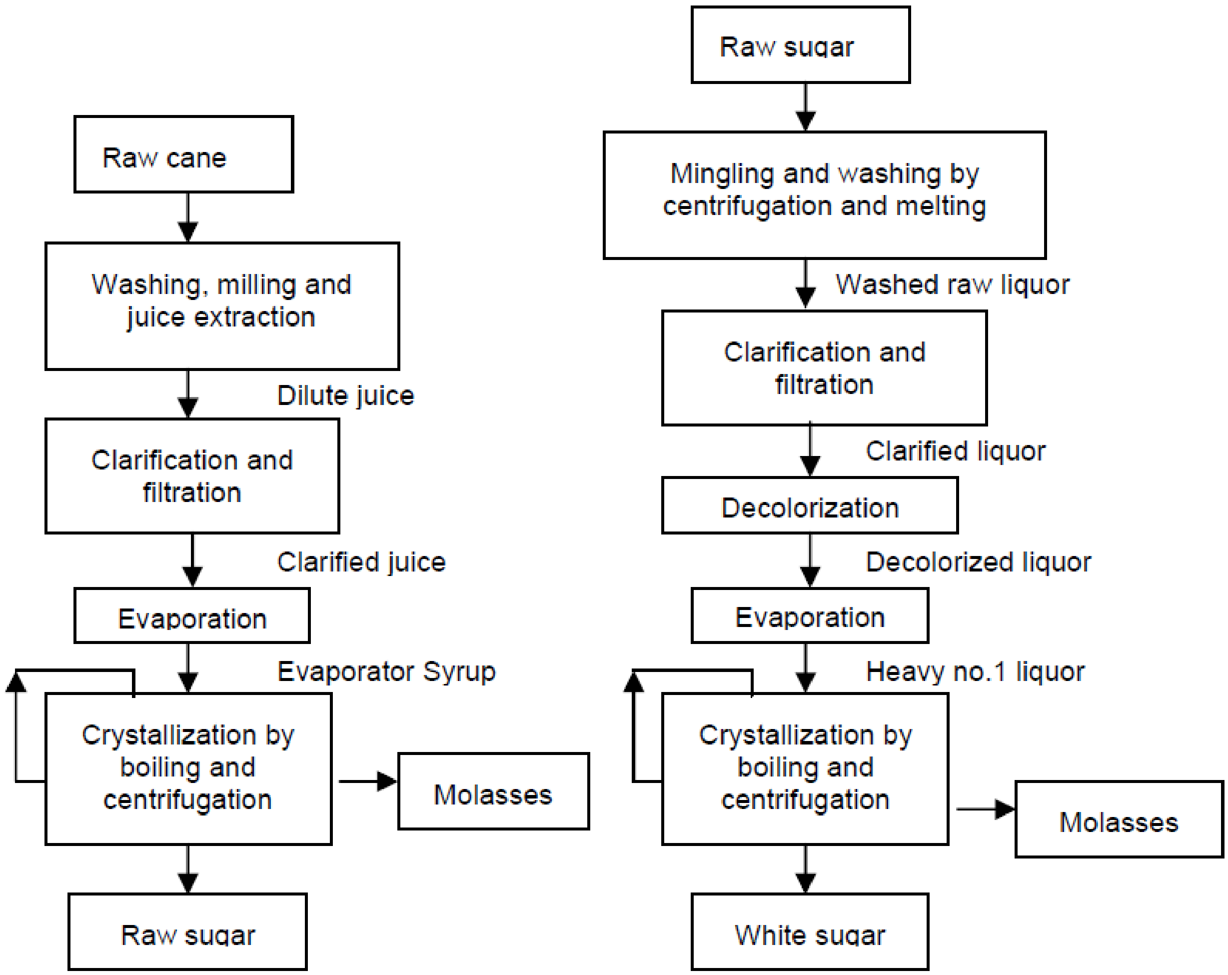


Figure 2.2 Flowchart of the typical unit operations for the processing of refined cane sugar (Clarke et al, 1997).

Table 2.1 Purity of sucrose reported in the scientific and technical literature.

Purity (% of sucrose)	Source of sucrose	Reference
99.96%	White refined sugar, SNS	Asadi 2005
99.96%	White refined sugar, SNS	Colonna and others 2000
99.96%	White refined sugar, SNS	Potter and Mansel 1992
99.95%	Beet and cane white refined sugar	Asadi 2007
99.95%	Beet and cane white refined sugar	Morgan 1999
99.90%	White refined sugar, SNS	Clarke 2000
99.90%	White refined sugar, SNS	Vaccari and Mantovani 1995
>99.8%	Beet and cane white refined sugar	Dowling 1990
99.7-99.8%	White refined sugar, SNS	Bensouissi and others 2007
≥99.7	White sugar	COMESA/FDHS 2004
99.70%	Beet and cane white refined sugar	European Economic Community 1973
99.70%	Beet and cane white refined sugar	Schiweck and Clarke 1994
≥99.5	Plantation or mill white sugar	COMESA/FDHS 2004
99.50%	Chinese cane white granulated sugar	China GB13104-2005

SNS – source not specified

Table 2.2 Composition of refined white beet and cane sugar (Godshall 2013).

Constituent	Cane	Beet
Pol	99.95	99.95
Color, pH 7	15-35	20-45
Abs ratio pH9/pH4	1.5-4.0	1.3
pH	6.2-6.7	6.5-8.0
Conductivity Ash %	0,01-0.03	0,01-0.03
Moisture %	0.01-0.02	0.01-0.02
Polysaccharides, ppm	70-200	20-50
Dextran, ppm	34-137 (M=63)	none unless infected**
Starch, ppm	30-50	0
Raffinose	0	30-50 ppm +
Kestoses	30-50 ppm +	0 to trace
Floccing potential	Low to none	Low to none
Causes of floc	Protein & ISP*	Saponins
SO2, ppm	Not detected	ND in USA, low in Europe
Sediment, ppm	10-20	
Turbidity, IU	2-25	1-5 (Higher outside US)
Turbidity, NTU	0-1.5	
Glucose, %	0.005	0.001-0.003
Fructose, %	0.005	0.001-0.003
Volatile compounds odor	Caramel, molasses	Earthy, VFA
Total plate count, CFU/10 g	<10	<10
Yeast & mold, CFU/10 g	<10	<10

* ISP is indigenous sugar cane polysaccaride, an arabiogalactan polymer
**Dextran infection (Leuconostoc sp) rarely occurs in beet sugar, but can occur if conditions are right

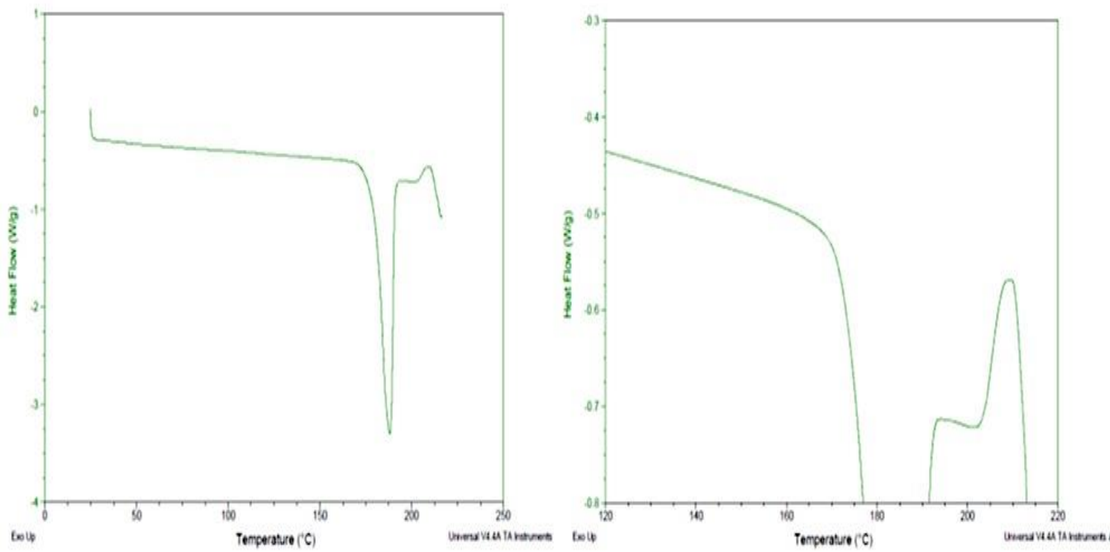


Figure 2.3 DSC thermogram of beet sugar heated from 25-220°C at 10°C/min (Lu and others 2013).

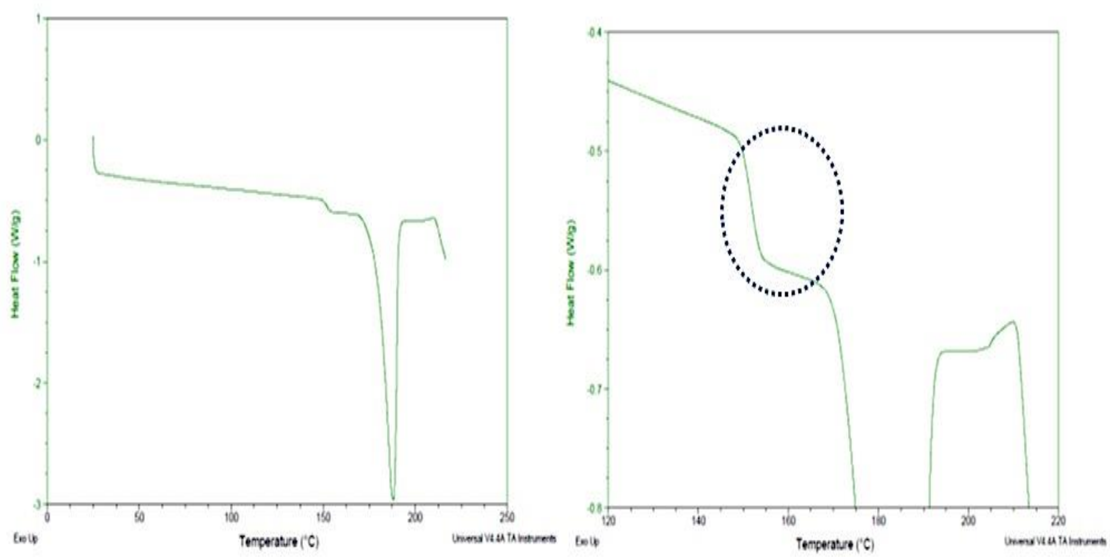
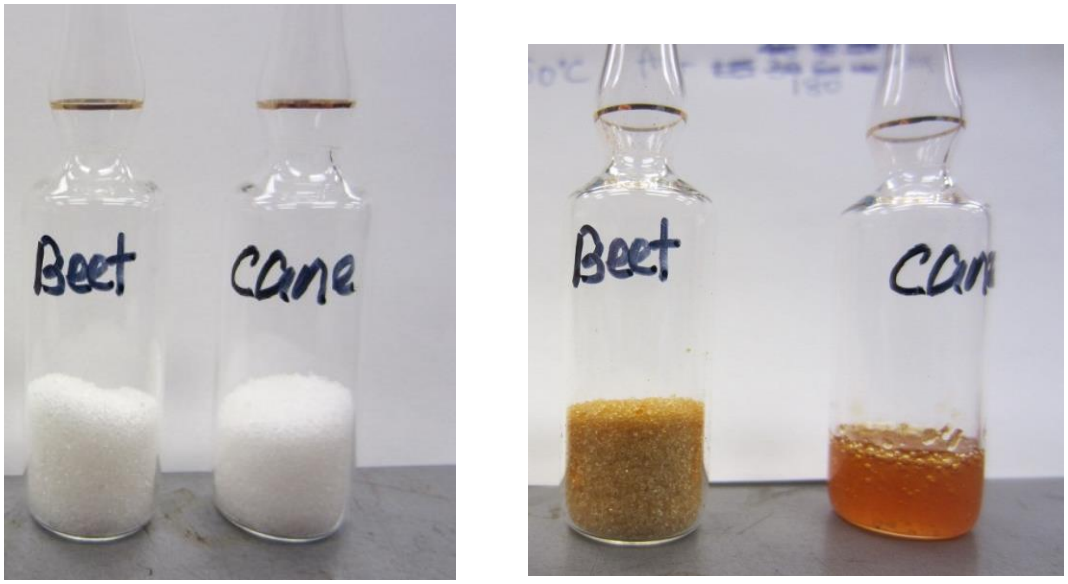


Figure 2.4 DSC thermogram of cane sugar heated from 25-220°C at 10°C/min (Lu and others 2013).



Sugar samples 160°C holding for 180 minutes

Figure 2.5 Observation of color and phase change in United Sugar Corporation beet and United Sugar Corporation cane sugar samples held at 160°C in a GC oven (Lu and others 2013).

Table 2.3 Quotes from participants of online discussions who believe that there is no difference between the sugar sources.

Quote	Source
"I can't tell any difference, and I don't think anyone else can. The difference is where it is grown and some of the processing, but once it becomes sugar, there's no difference."	sfgate.com
"The sucrose from sugar beets and sugar cane is not only identical to one another, but each is the same as the sucrose present in fruits and vegetables."	sugar.org
"I've never thought there was any significant difference between beet and cane sugar"	home-ec101.com
"Consumers cannot discern any differences between beet sugar and cane sugar in taste, appearance, and use. "	vegsource.com
"From cookies to cakes to bread to pancakes to candy -- candy! Molten sugar! -- No difference."	chowhound.chow.com
"in my experience, for most baking and cooking applications, it doesn't make a difference."	chowhound.chow.com
"It makes no difference to the recipe"	food52.com
"Having cooked with both beet sugar and cane sugar, I can say I saw no difference in the taste of the finished product."	city-data.com
"...there are no notable differences between the two. In fact, many producers often switch the source of sugar between beets and cane, and sell them in the same packaging, while the consumers are none the wiser."	differencebetween.info
"It doesn't matter any more which you use."	kelleybees.com
"In a process, beet sugar behaves the same as cane…"	forums.gardenweb.com
"I use beet sugar in cookies, cakes, pies, bread, whatever and don't notice a difference."	forums.gardenweb.com
"The only difference is that beet sugar is made from sugar beets, and cane sugar from sugar cane"	food-info.net

Table 2.3 (Cont.)

Quote	Source
"I bake a lot, and use both and have never noticed any difference… I also have noticed no performance difference whether baking or candy."	discusscooking.com
"In more than 55 years of baking and cooking I have never noticed a bit of difference and I make no effort to check the package to see how or from what the sugar was refined."	discusscooking.com
"…sugar from beets was shown to perform as functionally equivalent to cane sugar, with no discernable taste differences found in products evaluated in sensory testing"	spreckelssugar.com
"I've never noticed a difference and use whatever is cheapest when I need to purchase (almost always beet sugar)."	cookingjunkies.com
"It's quite possible that preparation and purification methods might give different tastes (impurities) in the two sorts but basically, they are identical."	cookingjunkies.com
"I've used beet sugar when cane sugar was oddly "missing" on the shelves. Didn't really notice any difference, but I still try to buy cane sugar."	cookingjunkies.com
"There is chemically no difference between the two sources, they just come from different plants...There can be slight variations in the way the sugar is extracted and processed that can affect the taste/quality. Moisture levels at harvest for either can differ, making a slight difference. Most people would never notice this as it's so very slight."	chowhound.chow.com
"But I personally have never noticed a difference."	chowhound.chow.com

Table 2.3 (Cont.)

Quote	Source
"Differences that are attributed to beet v. cane sugar can be explained a number of ways, including -- most significantly -- granule size (more on that in a minute). In any case, even the American Sugar Alliance, a consortium of beet and cane sugar companies says, "There is no difference in the sugar produced from either cane or beet." As Jason points out, sucrose is sucrose, and refined white sugar is 99.95% pure. Even assuming that that last 0.05% is wildly different in beet and cane sugars (it's not, but whatever), there are so many other variables in baking that that tiny bit -- especially that tiny bit accompanied by many other ingredients -- is insignificant"	forums.egullet.org
"I have never noticed a difference in 40 + years of cooking between cane and beet sugar."	chowhound.chow.com
"I have used these sugars interchangeably any time I have had beet sugar in my cupboard."	chowhound.chow.com
"I've never noticed a difference----it is white and odorless to most."	chowhound.chow.com
"I grew up baking with beet sugar (many sugar beets raised in Minnesota) and all our baked goods came out just fine. Maybe there are subtle differences in side-by-side tests, though as liegey says, sugar is purified to 99.9% sucrose, so it sure doesn't seem like the source should make a difference."	chowhound.chow.com
"While living in Germany, all the sugar was beet sugar - I never noticed any significant difference."	chowhound.chow.com
"refined white sugar is refined white sugar… is refined white sugar."	joepastry.com
"However claims that beet sugar creates “coarse” baked goods, smells bad, has a lower melt point, “burns” rather than caramelizes…it’s a bunch of hooey."	joepastry.com

Table 2.3 (Cont.)

Quote	Source
"Beet sugar is no different from cane sugar. In fact, a substantial quantity of table sugar on the market is from sugar beets"	community.diabetes.org
"Beet sugar and cane sugar are effectively interchangeable."	community.diabetes.org
"The white sugar is pretty much the same but the molasses (for rum) is a lot different between beets and cane."	homedistiller.org
"Both sugars are sucrose, and the difference in cooking is so small that it would be almost impossible to tell one from the other."	apps.exploratorium.edu
"I have never tasted a difference…"	cakecentral.com
"Sucrose is sucrose. Doesn't matter at all where it came from."	experienceproject.com
"both are used to make refined sugar, you cannot tell the difference in most cases."	experienceproject.com
"Once beet and cane sugar are refined, they are chemically identical."	beesource.com

Table 2.4 Quotes from participants of online discussions who believe that there is a difference between the sugar sources.

Quote	Source
Bakery owner who accidently substituted beet for cane sugar and her baked goods didn't turn out right	sfgate.com
"It matters in recipes for baked goods like angel food cake. It just isn't right with beet sugar. Lazy Daisy Cake, a wonderful old sponge cake from the past, is a real problem when it's made with beet sugar. It's coarse. All of those types of recipes are different."	sfgate.com
Crème brulee- white beet sugar we refused to caramelize on top	sfgate.com
"I always order C & H," he says. "When I make caramel, it seems to be cleaner. And it 'snaps' better when I make brittle and things like that."	sfgate.com
"Those impurities can wreak havoc in baking. Cane sugar is by nature a "cleaner" product. There are flavor differences as well, but they can be hard to detect unless you taste them side-by-side. If you want consistent results in baking, always use cane sugar."	home-ec101.com
"My aunt is a master baker and won't use beet sugar for her cakes or desserts at all. "	home-ec101.com
"If I am going to take the time to bake then I am only going to use the very best ingredients i.e. Pure Organic Cane Sugar"	home-ec101.com
"While to the inexperienced eye and palate both sugars appear the same, there are features that set cane and beet sugar apart… Professional bakers prefer cane sugar because it has a low melting point and blends easier."	ehow.com
"I just gotta say...Cane Sugar rules in my house!!"	chowhound.chow.com

Table 2.4 (Cont.)

Quote	Source
"I don't know about baking, but I have made sure lately to buy pure cane sugar for my sugar bowl. I find it has greater granular uniformity, and no "dust."	chowhound.chow.com
"Cane sugar tastes sweeter and doesn't go a funky color when it gets wet going down the drain. There's also Crème Brulee, which won't caramelize if you use beet sugar; it will just burn. Cane sugar gives superior results in cooking and baking, and since it has not been sprayed with Roundup, it is the best choice IMHO."	chowhound.chow.com
"there are slight differences between beet and cane sugar."	chowhound.chow.com
"Oh yes there is and all you have to do is prepare exact same recipes side by side to find the difference...With beet sugar caramel sauces become gummy and gluey. Baked goods have a much coarser texture. "	chowhound.chow.com
"I have noticed a significant difference between sugar beet sugar and cane sugar in a number of scenarios: For your average drop cookie, beet sugar will likely work fine. But it does tend to flatten baked goods- I have found that sugar beet baked goods do not rise properly. So if you are making a fluffy cake, you want pop overs or muffins with perfect tops, I wouldn't recommend beet sugar... But it [beet sugar] is of lower quality- and whenever you are working with something that is a bit cheaper, it has down points. I tend to use beet sugar only when nothing else is available. I find beet sugar does work well to make syrups and solutions..."	food52.com
"My wife is extremely picky about her baked goods and she swears by cane sugar."	city-data.com
"My choice is always going to be cane sugar because I *know* I can tell a difference in my baked goods and I love the results that cane sugar gives me."	thesweetchemist.com
"I generally make no-commercial-pectin preserves and cane sugar is all I use. Some might disagree, but I feel there is a difference in flavor. "	forums.gardenweb.com

Table 2.4 (Cont.)

Quote	Source
"I do see a difference...as one previous poster stated regarding "fine cooking". In several of the food science classes and baking classes I have taken a number of recipes were tested (blind testing) using beet sugar vs. cane sugar. Recipe results produced very real differences. Beet sugar reacts differently when cooked. A test doing a simple meringue resulted as follows: Beet sugar produced a sweeter taste with less loft when beaten and would "weep" quicker than cane sugar. Cane sugar, with the same recipe, produced great loft with a firm yet delicate meringue."	forums.gardenweb.com
"I just can not use Cane Sugar. I don't even like the taste of Cane Sugar as it is just to sweet and makes my cookie dough too gooey for my cookie press."	forums.gardenweb.com
"I do not care for beet sugar. I think it's granules are too granular."	discusscooking.com
"When creaming my sugar & butter together at Christmas time last year it never quite reached the texture I was expecting, nor did the dough handle normally (was making kringla) using beet sugar."	discusscooking.com
"I prefer cane sugar."	discusscooking.com
"To me beet sugar is sweeter, no difference in flavor."	discusscooking.com
"Cane only here - I can give you a list of disasters using beet. Especially in candy making and anything you need to set up."	discusscooking.com
"As far as a difference in flavor, I do notice one. I also find that beet sugar doesn't dissolve as readily as cane sugar."	discusscooking.com
"I've only ever used cane, but, I knew a woman in Arizona that despised the beet sugar. She said it did not taste the same or bake the same."	cookingjunkies.com

Table 2.4 (Cont.)

Quote	Source
"I read somewhere that when both beet sugar and cane sugar are refined there are a few leftover fructose molecules in the sugar (table sugar or sucrose consists of a molecule of glucose and a molecule of fructose). The cane sugar contains more of these extra fructose molecules than the beet sugar does. Some people say they can't tell a difference in the taste but I definitely can. To me beet sugar just tastes sweet. Cane sugar tastes sweeter and tastes like sugar should; it tastes like sugar. I really noticed the difference when I made homemade ice cream one time. I used the same recipe I'd always had and I knew I had measured everything perfectly, but for some reason it just didn't taste as sweet as it should have and the flavor wasn't right either. It was then that I noticed that the bag of sugar I bought said, "Made with sugar beets." The next batch was made with cane sugar and it made all the difference in the world."	cookingjunkies.com
"There are slight but important chemical differences between beet and cane sugar, and these differences are responsible for the differences in the way beet and cane sugar behave in cooking and baking. Most notably, beet sugar will not caramelize; it burns instead. The molecular differences are in the carbon atoms of the molecule: C4, C3 differences, and in the ratio between the 13c and 12c isotopes. These differences are slight, but enough to cause differences in the way the two sugars react chemically in recipes. The lack of caramelization and beet sugar's tendency to crystalize when making buttercream frosting (among other examples) are described in the San Francisco Chronicle story linked to above."	chowhound.chow.com
"For starters, I simply don't like beet sugar. I swear I can taste a difference. But I've also had bad results with beet sugar in icings and candy. As a result I only buy cane sugar, almost always C&H. For the record, I don't think I've ever seen a confectioner's sugar made from beets. That should say something, even if it's only that I'm blind. "	chowhound.chow.com
"I find that 100% cane is best for pulled sugar work, either kind works well for caramel and, frosting and candies."	chowhound.chow.com

Table 2.4 (Cont.)

Quote	Source
"The rule of thumb I learned (about the time the first article came out), use cane sugar in baking because many of the old recipes were written for cane sugar; and cane and beet sugar do not bake up the same."	forums.egullet.org
"In France where much of beet sugar come from, cane sugar is used in candy making and syrups as many people find beet sugar is more prone to crystallization. I haven't experimented with this as I use cane sugar but suspect there may be more than a grain of truth here! "	realbakingwithrose.com
"Every time I caramelized sugar at my grandmother's house it worked beautifully--I never used water, swirled it a bit and got beautiful caramel. I'd go home and I'd get an evil, seized mess... She only uses Dominos sugar. I used whatever was on sale. Dominos is pure cane sugar. Most other supermarket sugars in Michigan are beet sugars. A pastry chef told me that beet sugar has a lot more impurities than cane. He was demonstrating sugar work by boiling sugar (with a good bit of water) and skimming off a gray scum that kept appearing. Now if I'm going to make caramel, I make sure its cane sugar. It may lump up a bit early on, but it always melts out before it's done."	chowhound.chow.com
"One major difference I've found between beet and cane is in the making of Swiss and French Meringues...for reasons that I can't begin to understand, after several attempts, I could never get the beet sugar to dissolve properly, creating either gritty French meringue or un-fluffable Swiss Meringue...I was really - and still am- flummoxened by this."	chowhound.chow.com
"...I cook and bake my entire life in Italy and we have beet sugar. I have notice that caramel etc. come out much better with American sugar (cane, white). In Italy I had hard time making dry caramel and sometimes caramel in general..."	forums.egullet.org
"I went to a demo once by Michael Recchiuti who wrote "Chocolate Obsession" with Fran Gage. At any rate, the entire basis of a lot of his recipes relies on his "burnt caramel"...they specifically mentioned to use cane sugar and avoid beet sugar at the demo. I guess they feel that there is a real difference in the outcome."	forums.egullet.org

Table 2.4 (Cont.)

Quote	Source
"Finally someone else smells it too. Beet sugar smells earthy to me like dirt."	forums.egullet.org
"I definitely can smell it, and don't like it at all."	forums.egullet.org
"Yeah, I didn't know that's what I was smelling either until I read the thread."	forums.egullet.org
"So I have just made a batch of the passion fruit/mango caramels with it and poured them into the bars. Scraping the pot, the caramel seems to be firmer than the version made with cane sugar, but is still quite tender to chew."	forums.egullet.org
"Don't use it in cake. I've done several recipes both ways and the beet are tough and mealy."	chowhound.chow.com
"The first time I found a difference was when i was making a caramel sauce. It was not that it caramelized faster, it was the end product. It glued forks to plates. The stuff stinks too. "	chowhound.chow.com
"There was some preference for cane, though she could only say that beet sugar does not caramelize - so it can't be used on crème brulee and the like. I've noticed that cane sugar does not lump as much. "	forums.egullet.org
" I understand the chemical makeup of refined sugar whether from cane or beet might be identical, but they do not taste or perform identically in my experience... Having grown up with it, and my cooking grown up with it, buying a bag of store-brand granulated sugar in an effort to economize years ago was a shock. Not indicated to be cane on the label and therefore probably beet, the flavor was terrible! And the texture was slightly gummy, compared to C&H. And there was no lovely C&H almost-vanilla aroma, neither. Yuckers. Never again--ever since I economize in other ways. "	forums.egullet.org
"I know that when I've made caramel in the past, one of these sugars boils up much higher in the pan than the other (although the quantity and temperature are the same), I just can't remember which one, which leads me to believe that there is some chemical difference between beet and cane."	forums.egullet.org

Table 2.4 (Cont.)

Quote	Source
"My father (a scientist) said the same thing about cane and beet sugars being the same. You are wrong. They perform differently. Beet sugar is more difficult to caramelize. Try them side by side if you don't believe me."	forums.egullet.org
"I heard cane sugar is better for baking and candy making."	joepastry.com
"Sugar is not sugar. Beet sugar is not used in candy making because it doesn't silk. Cane sugar has to be used to make candy. So there is definitely something different about the two types. Now for fermenting I prefer the beet by far."	homedistiller.org
"While perhaps theoretically all white sugar is the same, beet sugar and cane sugar do vary by a small percentage, in spite of what the sugar beet industry may say. Does 0.05% matter in taste? Depends on the taster. Does it matter in final product? You bet! Whether it is cookies, cake, candy, bread, or alcohol, differences will carry over, unless perhaps you are making neutral. "	homedistiller.org
"Actually, if you had a little pile of cane sugar and a little pile of beet sugar you could tell the difference right off the bat. Beet sugar crystals are larger and therefore sparkle more. When beet sugar is used in baking, etc., it will not break down and incorporate as is typical of cane sugar. Your mixture will remain gritty and the end product will not be as intended. I won't go near beet sugar. It is a bit cheaper, but not worth the difference in performance and end product."	community.qvc.com
"Beet sugar does not taste as good as cane sugar. It has a weird wang to it ha ha."	cakecentral.com
"They smell quite different. I use cane."	cakecentral.com
" I know that not one person who has ever used beet sugar in a canning recipe has ever won a blue ribbon at any state or county fair. That is because cane sugar really does taste better in jams, jellies, preserves and canned fruit. Also, I am aware that cane sugar has a lower charge on the glycemic index and therefore is probably better for us than beet sugar. The increase in beet sugar use, along with high fructose corn syrup, has probably contributed to obesity."	experienceproject.com

Table 2.4 (Cont.)

Quote	Source
"Beet sugar is the "local" product here, so I usually buy it for every day. In my own opinion I find it to be not quite so fine, it cakes a little easier and it has a certain (not unpleasant to me) slightly earthy smell."	community.cookinglight.com
"I buy C&H when I'm flush, or Florida Crystal, which I like best, but the only major difference I notice using beet sugar (store brand, Pioneer) in most baked goods is that it clumps more easily. It definitely absorbs moisture more readily-- but I believe it also makes less of an environmental impact, production-wise....I think beet sugar is probably better for some things-- it has a very neutral sweetness, to me. That can be useful."	community.cookinglight.com
"we found a difference in taste between sugar made from beet and that made from cane. It was most noticeable to us when recreating preserves we knew from back in South Africa, where only cane sugar is available. We prefer the cane sugar but I suspect that this will differ from person to person. As a rule the difference is less noteable in pickles."	cottagesmallholder.com
"In its fully refined 100% pure state, sucrose should not taste any different from source to source, however it is the little impurities that are part of a particular process and the source of sugar which add those different nuances."	cottagesmallholder.com
"Using beet sugar is not a good idea at all in frostings, jellies, and many cakes."	beesource.com

Table 2.5 Quotes from participants of online discussions who believe that there are differences between beet and cane sugars in some applications and no differences in difference in other applications.

Quote	Source
"Chemically speaking table sugars refined from cane and beet sugar are quite similar, but there is a minute chemical difference that worries some cooks. Cane sugar may caramelize better than beet, but the difference may not be noticeable to most. (That doesn't mean that highly skilled cooks and industry professionals wouldn't notice the difference). The main source of contention seems to be the behavior of refined beet sugar in baking."	home-ec101.com
"White beet sugar and white cane sugar are virtually identical in composition, but there may be very small differences (~0.05%) which some cooks find affects caramelization. Reportedly, cane sugar will caramelize better than beet sugar in many cases."	cooking.stackexchange.com
"I don't think it matters for everyday home baking, but may make a difference when you are making higher skill level products and base for buttercreams. "	food52.com
"There's a difference in how they brown on top of crème brulee, which certainly counts as fine baking... but otherwise they're very similar. (For the record, beet sugar turns almost immediately black under the torch, while cane sugar turns golden-brown.)"	forums.gardenweb.com
"Martha Stewart, the culinary obsessive-compulsive, tested cane vs. beet sugar in cooking. Her test kitchen didn't notice a discernable difference except in fine baking, especially cakes. There they could tell the difference between cane and beet sugar."	forums.gardenweb.com
"Personally I haven't seen any difference, between cane or beet sugar, in anything I cook but they do smell different... The first time I noticed the earthy smell of beet sugar I thought the packaging had adsorbed the odor from something else and tossed out a five pound bag of sugar."	forums.gardenweb.com
"Depends on who you want to believe. The sugar industry says there is no difference in taste or performance. Some testers believe there is a minor difference in taste and performance."	discusscooking.com

Table 2.5 (Cont.)

Quote	Source
"Beet sugar smells funny. But I haven't found any difference when cooking with it vs. cane sugar."	cookingjunkies.com
"There was an article I remember reading way back about the difference between cane & beet sugar. In the end, it came down to them being different grain sizes which can affect baked goods (especially those involving meringues or creaming butter). Once it's dissolved, all sugar was indistinguishable. Oh, one other difference is some vegans don't consider cane sugar vegan since it's filtered through bone char. "	forums.egullet.org
"One thing I notice is that raw beet sugar stinks. Not sure what it smells like, but it's a little "feety". However, for most uses, I haven't noticed a performance change from the cane sugar, just the putrid smell when I'm measuring the raw sugar, a smell I've grown to dislike."	forums.egullet.org
"I live in Turkey where we get beet sugar, and as I was reading the thread, I found myself wondering when someone would mention the smell. I don't notice it in anything I make with it, but when I open the container where the sugar is stored, the smell that hits me is not really pleasant."	forums.egullet.org
"I have to admit that I wasn't really aware of whether I might be getting cane or beet sugar until rather recently, despite the fact that I grew up near a rather large sugar-beet-producing region in Michigan. (Oddly enough, it was moving to another large sugar-beet-producing region in Belgium that bumped up my awareness.) That said, your comment about bad smells reminded me of how I always hated the smell of my mom's sugar container when I was a kid, and since she buys it from a Michigan beet farming cooperative I now know that it was beet sugar. Not that it made baked goods smell or anything, and maybe refined white cane sugar smells the same (but raw cane sugar, which does not smell the same in my opinion, and some powdered grape sugar are all I have on hand, so I can't say at the moment)."	joepastry.com

Table 2.5 (Cont.)

Quote	**Source**
"I have to say that I can notice a difference in smell, but maybe that's down to how the sugar is processed, as I live in Asia and the local sugar here smells quite different from the beet sugar I'm used to from Europe. I can't really put my finger on it, but some sugar here smells sort of sickly sweet in a strange way. That said, the taste seems to be the same and I haven't noticed any difference when using it for baking."	joepastry.com
"THAT IS UNLESS, you're using the sugar for a frozen product. I insist upon beet sugar for my gelato production because of the temperatures at which the sugars freeze is different, as well as altering the "Brix" of my Sorbettos. This is the only real area where I've noticed a difference. "	apps.exploratorium.edu
"Not only can I not tell the difference, the beet sugar has the advantages of costing less and being vegan."	cakecentral.com
"I've never noticed a difference in taste, but here in the UK the locally produced beet sugar doesn't produce icing quite as white as cane sugar does."	cakecentral.com
"Once beet and cane sugar are refined, they are chemically identical. But they don't taste exactly the same. In a recipe you can't tell the difference, but tasting a spoonful by itself I can taste the difference."	beesource.com

Chapter 3: Sensory differences between beet and cane sugars determined by the tetrad test and characterized by descriptive analysis

3.1 Abstract

Commercially, sucrose is predominantly extracted from sugar beet and sugar cane. Sugar from either source is composed of greater than 99% sucrose. Despite their nearly identical chemical identities, beet and cane sugars differ in their analytically determined volatile profiles, thermal behaviors, and minor chemical compositions. However, scientific evidence concerning the sensory properties of beet and cane sugars is lacking. The objectives of this research were to: 1) determine whether a sensory difference was perceivable between beet and cane sugar sources and 2) characterize the difference between the sugar sources using descriptive analysis. One hundred panelists evaluated sugar samples by aroma-only, taste and aroma without nose clips, and taste-only with nose clips using a tetrad test. A significant difference ($p<0.05$) was identified between beet and cane sugar sources when evaluated by aroma-only and taste and aroma without nose clips. However, there was no difference when tasted with nose clips. To characterize the observed differences, ten trained panelists identified and quantified key sensory attributes of beet and cane sugars using descriptive analysis. Analysis of variance (ANOVA) indicated significant differences ($p<0.05$) between sugar samples for eight of the ten attributes including: off-dairy, oxidized, earthy, and barnyard aroma, fruity and burnt sugar aroma-by-mouth, sweet aftertaste, and burnt sugar aftertaste. Principal component analysis (PCA) and cluster analysis showed two distinct groups, one for beet sugars and the other for cane sugars. The sensory profile of beet sugar was characterized by off-dairy, oxidized, earthy, and barnyard aromas and by a burnt sugar aroma-by-mouth and aftertaste, while cane sugar was characterized by sweet and fruity attributes. This study illustrated that beet and cane sugar sources can be differentiated by their aroma and provides a sensory profile to characterize the differences. As sugar is used mainly as an ingredient, sensory differences between beet and cane sugar sources once incorporated into different product matrices should be studied as a next step.

3.2 Introduction

Sucrose, otherwise known as sugar, is an important commodity worldwide, because of its influence on the sensory, physical, and chemical properties of a variety of food products. Sugar is readily formed in plants as a product of photosynthesis. Sugar beet (*Beta vulgaris*) and sugar cane (*Saccharum officinarum*) are the most common plant sources for commercial scale sucrose extraction. Sucrose is recovered from the leaves and stalks of sugar cane and from the roots of sugar beets (Colonna and others 2000). The extracted sucrose is processed to yield white granulated sugar. The resultant sugar is comprised of greater than 99% sucrose, regardless of its source, though differences in their volatile profiles, thermal behaviors, and minor chemical compositions have been noted (Potter and Mansel 1992; Colonna and others 2000; Asadi 2005). Remnants from the sugar plant source and processing methods, along with water, constitute the remainder of the composition (Colonna and others 2000).

Though the chemical composition of beet and cane sugars are nearly identical, differences in their sensory profiles have been suggested. Monte and Maga (1982) performed a preliminary sensory study, which indicated a statistical difference between beet and cane sugars, particularly their odors. The study also revealed that temperature and concentration of the sugar solution samples were influential factors in the detection of a difference between beet and cane sugars.

Monte and Maga (1982) conducted a triangle test which allowed them to only determine if the difference existed. Thus,, the details of the sensory attributes that differ between the sugar sources remain to be elucidated. Based on previous literature, it is probable that panelists' perceived off-aromas in the beet sugar, allowing them to discern a difference between the sugars. Beet sugar is often described in the literature as having an objectionable earthy and musty aroma based on instrumental analysis (Acree and others 1976; Parliment and others 1977; Monte and Maga 1982; Marsili and others 1994; Pihlsgard 1997; Magne and others 1998). Analytical flavor chemistry techniques have attributed this off-aroma in beet sugar to geosmin and to a variety of fatty acid compounds (Marsili and others 1994; Godshall and others 1995; Moore and others 2004). These volatile compounds are associated with the microbial contamination from the soil, the beet root itself, and the breakdown of plant parts (Marsili and others 1994; Godshall and others 1995; Clarke and others 1995; Lu and others

2003). Although the flavor profile differences between beet and cane sugars have been explored using analytical chemistry techniques, the differences have yet to be characterized using sensory descriptive analysis.

Eating is a cross-modal experience that combines aroma, taste, and tactile perceptions. Flavor perception is influenced by the interaction between these different sensory modalities (Laing and Jinks 1996; Belitz and others 2004). Due to the complexity of flavor, aromas are frequently confused as tastes. To isolate taste from the other sensory perceptions, nose clips are often used (Murphy and others 1977; Murphy and Cain 1980; O'Mahony 1991; Abegaz and others 2004). The nose clip closes the nostrils, blocking aroma input, and, in turn, retronasal aroma perception. Therefore, before characterizing the sugar using descriptive analysis, it was first important to determine whether panelists could perceive a difference between beet and cane sugars with and without nose clips.

The objectives of this research were to: 1) determine whether a sensory difference was perceivable between beet and cane sugar sources in regard to their aroma-only, taste and aroma without nose clips, and taste-only with nose clips and 2) characterize the difference between the sugar sources using descriptive analysis. In view of the analytically determined volatile profile differences between beet and cane sugars, it was hypothesized that the sugars would differ in their aromas and that sugars from beet sources would receive higher ratings for off-aromas compared to cane sugars in the descriptive analysis.

3.3 Materials and Methods

<u>Sample Selection</u>

Two brands of beet sugar, Pioneer Sugar and United Sugar Corporation, and two brands of cane sugar, C&H and United Sugar Corporation, were used in this study (Table 3.1). The beet and cane sugars from United Sugar Corporation were donated and the Pioneer Sugar and the C&H were purchased from a local grocery store (Urbana, IL).

Tetrad Test

Sample Preparation

Initial instrumental screening and previous R-index results indicated that sugars of like sources from different manufacturers are nearly the same (Urbanus 2014 Chapter 4). Therefore, one brand of beet sugar, Pioneer Sugar, and one brand of cane sugar, C&H, were chosen to be used in the tetrad test as representative beet and cane sugar samples. To prepare the sugar samples, plastic 29.5-mL cups with lids (Solo Cup Company, Inc., Chicago, IL), labeled with a randomized three-digit code, were filled with approximately one gram (1/4 tsp) of sugar.

Panelists

A total of one hundred panelists (77F and 23M, age range 18-55 yrs) participated in the tetrad test. Participants were recruited through a departmental e-mail listserv and by flyers posted in campus buildings. The panelists were screened based on interest and availability, which were indicated on a screening survey (Figure 3.1). Panelists were instructed not to eat or drink at least 30 minutes prior to their scheduled session times. All panelists were compensated monetarily at the completion of the study.

Test Design

The tetrad test took place in a room with partitioned booths maintained at 22^{o}C and 33% relative humidity. Panelists evaluated the samples under incandescent lighting. Panelists attended one, 15 to 20 minute session, in which they evaluated 12 samples. The samples were presented to the panelists in three sets of four samples. Each set of samples corresponded to different evaluation conditions: aroma-only by orthonasal sniffing, taste and aroma-by-mouth without nose clips, and taste-only by mouth with nose clips (Bettertimes, Santa Fe Springs, CA). The nose clips closed the panelist's nostrils to prevent retronasal olfactory perception. The order of the sets and the samples within each set were randomized per panelist. Randomization was generated by the Compusense *five* Plus (Version 5.0: Guelph ON, Canada) data acquisition system using a William's Latin Square design.

Each panelist was served their first tray of samples along with warm and room temperature rinse water. For samples evaluated by taste and aroma-by mouth without nose clips and taste-only by mouth with nose clips, the panelists were instructed to rinse with warm (26 to 29°C) and room temperature purified water (Absopure, Urbana, IL) before the first sample and between subsequent samples, expectorate all rinses and samples, and to taste the entire contents of the cup at once. Panelists were served the four samples of tetrad side-by-side and asked to evaluate the samples in the order from left to right. Their task was to sort the samples into two groups of two samples based on similarity. There was a one-minute break between each tetrad set. This protocol was repeated with the second and third set of samples.

Data Analysis

The raw data were collected using Compusense *five* Plus (Version 5.0: Guelph ON, Canada) and analyzed using IFPrograms™ software (Version 8.1: Richmond, VA). The program computed values of d', and binomial probabilities (p-values) for sample differences. d' is a measure of the estimated sensory difference between samples. The calculated p-values were compared to 0.05 significance level to determine if a significant difference existed.

Descriptive Analysis Panel

Sample and Reference Preparation

In the United States, there are a limited number of beet and cane sugar manufacturers. Therefore, two brands of beet sugar, Pioneer Sugar and United Sugar Corporation, and two brands of cane sugar, C&H and United Sugar Corporation were chosen as representative beet and cane sugars and used in the descriptive analysis test (Table 3.1). To prepare the sugar samples, plastic 29.5mL cups with lids (Solo Cup Company, Inc., Chicago, IL), labeled with a randomized three-digit code, were filled with approximately 12 grams (one tablespoon) of sugar.

Reference samples were prepared in plastic cups with lids (Solo Cup Company, Inc., Chicago, IL) labeled with the reference identity. A complete list of attributes, definitions, references, and reference preparation methods are provided in Table 3.2. All references were prepared no more than 24 hours prior to evaluation.

Panelists

Ten panelists (8F, 2M, age range 23-45 yrs) participated in the descriptive analysis portion of the study. Panelists were selected based upon interest, experience, aptitude, and availability. All panelists were University of Illinois graduate students who had prior experience participating in sensory descriptive analysis panels.

Test Design

Quantitative descriptive analysis (Stone and others 1974) was used to evaluate the sensory attributes of beet and cane sugars. The descriptive analysis panel took place over six sessions. The sessions were held on five consecutive days. Panelists attended one, 1-hour session per day with the exception of day five, in which panelists attended two, 30-minute sessions. Training was accomplished in four sessions, which took place in a conference room (Larson-Powers and Pangborn 1978; Piggott and Mowat 1991; Shamaila and others 1992). Sample evaluation took place during sessions five and six in a room with partitioned booths. The booths were maintained at 22^{o}C and 33% relative humidity with incandescent lighting. In between each sample and reference, panelists were instructed to rinse with warm water and room temperature water (Absopure, Urbana, IL). All samples, references, and rinses were expectorated.

On the first session, panelists were briefed on the use of scales and references to describe attributes of the sugar samples. After the brief introduction, panelists evaluated the aroma, aroma-by-mouth, taste, and aftertaste of the sugar samples and generated verbal descriptors for each sample that fit into those sensory modality categories. Panelists also generated references, which served as physical representations for the descriptors generated. These tasks were performed individually, followed by a group discussion.

During the second session, panelists evaluated the physical references generated from session one, in order to determine if the references adequately represented the sensory attributes of the samples. Panelists continued term generation and reference refinement during the second session. This procedure was repeated during the third session until panelists reached a consensus of generated terms and references by omitting redundant terms and refining the list to include only the most pertinent attributes used to describe the differences among the samples. The finalized list of terms and references was compiled (Table 3.2). Panelists, then, rated all of the finalized reference samples relative to sugar sample intensities for the specific attribute. An 11-point scale, zero to ten, represented the range of intensity of the attribute that panelists perceived in the sugar samples. Reference samples with intensities perceived to be greater than the strongest sugar sample for that attribute received scores above ten. Panelists' scores were compiled and the average rating for each reference was calculated. The average rating of each reference was used to anchor the scale that panelists used for sample rating (Table 3.3). Session four was used for panelist calibration in order to ensure consistency across the panelists. Panelists practiced rating samples with respect to reference intensities.

During the fifth and sixth sessions, panelists were instructed to review the references before entering the booths for sample rating. Once in the booths, panelists evaluated sugar samples for each of the attributes using an 11-point scale ranging from zero to ten. Verbal and written instructions for test procedures were provided to the panelist prior to evaluation. Panelists were presented with the sugar samples and asked to rate their perceived intensities on the specific attributes as compared to the anchored references. Samples were evaluated in duplicate over two sessions. Sample randomization and evaluation, and data collection were done using Compusense *five* Plus (Version 5.0: Guelph ON, Canada).

Data Analysis

Data collected from the panelists were compiled into a spreadsheet and analyzed using Microsoft Excel and XLSTAT (Version 2009: Addinsoft USA, New York, NY). Analysis of variance (ANOVA) was conducted for each of the ten sensory attributes to assess differences in the mean scores of the four types of sugar samples for each attribute. The calculated probabilities obtained from the analysis were compared to the significance level of 0.05. Adjusted F-values by mixed model ANOVA were calculated for attributes with significant judge-by-sample interaction. Judge-by-sample interaction was used as the error term for all attributes in this calculation. Fisher's least significant difference (LSD) was conducted on attributes determined as being significantly different by ANOVA. Agglomerative hierarchical clustering (AHC) was conducted by the Ward's method, with the clusters automatically truncated by the software. Principal component analysis (PCA) plots and a Pearson correlation coefficient matrix were also generated to show the relationship among the significant attributes.

3.4 Results and Discussion

For the tetrad test analysis, values of d', and binomial probabilities for sample differences are provided in Table 3.4. A significant difference was identified between beet and cane sugars when the samples were evaluated by aroma-only and taste and aroma without nose clips. However, samples could not be differentiated when tasted with nose clips. Because nose clips are intended to stop volatiles from entering the olfactory receptors in order to isolate taste perception, the data suggest that beet and cane sugars cannot be differentiated by their taste only. Differences between beet and cane sugars that were evaluated by tasting samples without nose clips can be attributed to retronasal aroma differences.

The descriptive analysis study was carried out to characterize the nature of the observed difference found in the tetrad test. In the descriptive analysis study, ten terms, including off-dairy aroma, oxidized aroma, earthy aroma, barnyard aroma, vanilla aroma, fruity aroma-by-mouth, burnt sugar aroma-by-mouth, sweet taste, sweet aftertaste, and burnt sugar aftertaste, were generated by panelists to describe the sample set. The attribute definitions and reference intensity ratings for each attribute given by the panelists are shown in Table 3.3. The reference intensities are an average of each panelist's ratings.

Analysis of variance (ANOVA) was conducted for each of the ten sensory attributes generated by the descriptive analysis panel and the results are summarized in Table 3.5. Judges scores were significantly different ($p < 0.05$) for eight of the ten attributes. This source of variation is common in descriptive analysis testing and may be due to panelists differing in their use of the scale when rating samples. All of the ten attributes were found to be significantly different ($p < 0.05$) across the sugar samples. Judge-by-sample interaction (J*S) was significant ($p < 0.05$) for eight of the attributes, which is telling of inconsistency among the panelists. To account for the variation due to panelists across the samples, adjusted F-values were calculated for attributes whose interaction was significant. Of the eight calculated adjusted F-values, six were noted as being significantly different, including off-dairy aroma, oxidized aroma, earthy aroma, barnyard aroma, fruity aroma-by-mouth, and burnt sugar aftertaste. The adjusted F-values are shown in Table 3.5.

Mean separation analysis by LSD was conducted and the attribute means for each sugar sample are given in Table 3.6. Mean attribute scores for C&H and United Sugar Corporation cane sugars were significantly different for two of the eight attributes: barnyard aroma and fruity aroma-by-mouth. Pioneer and United Sugar Corporation beet sugars were significantly different for the attributes of off-dairy aroma, oxidized aroma, barnyard aroma, and burnt sugar aroma-by-mouth. When comparing beet sugar versus cane sugar sources, significant differences existed between at least one beet and cane sample for all eight attributes. The findings provided evidence that there is more variation between sugar sources than between brands of like sugar sources.

The data generated by ANOVA were used to perform cluster analysis. The resulting dendrogram is presented in Figure 3.2. Pioneer and United Sugar Corporation beet sugar samples formed one cluster, while United Sugar Corporation cane sugar and C&H formed a second cluster. The distance between the beet and cane sugar clusters was much greater than the difference between the clusters of brands of like sugar sources. Again, these findings confirm those from the tetrad test and agree with previous findings, which identified a sensory difference in beet and cane sugar sources, particularly in their odor (Monte and Maga 1982).

Pearson correlation coefficients are shown in Table 3.7. Significant positive correlations were observed for off-aroma attributes, including off-dairy aroma, oxidized aroma, and earthy aroma, and between barnyard aroma and earthy aroma. Positive correlations were also observed between burnt sugar aroma-by-mouth and burnt sugar aftertaste. Oxidized aroma and sweet aftertaste were significantly correlated in the negative direction.

PCA plots (Figure 3.3) were constructed from the sensory ratings generated for each sugar type across all attributes. The PCA plots captured 96.57% of the total variation with 85.95% of the variance explained by factor 1. Factor 2 accounted for the remaining 10.62% of the total variance. Two clusters were formed opposite of one another on each of the plots. On the top plot, the cluster on the left is made up of the cane sugar samples and the cluster on the right is made up of the beet sugar samples. On the bottom plot, the cluster on the left includes sweet aftertaste and fruity aroma-by-mouth, while the cluster on the right is defined by off-aromas. Beet sugar samples are in close proximity to the off-aroma cluster on the plot, which includes off-dairy, oxidized, earthy, and barnyard aromas. Cane sugar samples were strongly associated with the sweet and fruity cluster on the PCA plot.

Data from the tetrad test suggested that beet and cane sugar sources can be differentiated by aroma but not by taste only. This is in agreement with the descriptive analysis results, which found no significant differences in taste attributes between the sugars. Hence, the differences between beet and cane sugar sources reside in their aroma characteristics, which, as suggested by the literature, can be attributed to their volatile profiles. Analytical flavor chemistry techniques have been previously used to identify the compounds responsible for the characteristic off-aromas in beet sugar. Geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol), in combination with volatile fatty acids, including butanoic acid isovaleric acids (3-methyl-butanoic acid) were found to have an odor identical to the off-aroma perceived in beet sugar (Marsili and others 1994; Godshall and others 1995; Moore and others 2004). These compounds emit an earthy, musty aroma, which is perceivable in beet sugar. The terms generated in the descriptive analysis study herein are in agreement with the analytically-determined flavor attributes reported in the literature to characterize beet sugar aroma.

Off-aromas in beet sugar originate from soil microorganisms, the beet itself, and from the degradation of the tops, leaves, or root of the beet (Marsili and others 1994; Godshall and others 1995; Clarke and others 1995; Lu and others 2003). Crystal growth takes place in a supersaturated solution. Once the crystal reaches the desired size, the syrup is separated from the crystals by centrifugation. Though most of the syrup is removed, a thin layer always remains. Most of the volatiles present in beet sugar reside in this thin outer layer of concentrated syrup surrounding the crystal (Clarke and others 1995; Godshall and others 1995; Colonna and others 1996).

Little published work is available on the elimination of off-aromas in beet sugar. Air circulation and ventilation of sugar during storage resulted in partial elimination of the off-odors in beet sugar (Clarke and others 1995; Colonna and others 1996; Duffaut and others 2004). Treatment suggestions, such as additional washing in the centrifuge, have also been proposed to aid in off-aroma removal (Clarke and others 1995; Colonna and others 1996; Duffaut and others 2004).

3.5 Conclusion

Although the composition of beet and cane sugar sources are nearly identical (>99%), data from the tetrad test suggested that they can be distinguished by their sensory properties. A significant difference ($p<0.05$) was identified between beet and cane sugars when panelists evaluated the sugars by aroma-only and taste and aroma without nose clips. No difference was perceived when tasting the samples with nose clips, which suggests that volatile compounds are responsible for the differences perceived between beet and cane sugar sources.

Data obtained via descriptive analysis characterized the differences identified in the tetrad test. Analysis of Variance (ANOVA) identified significant differences ($p<0.05$) between sugar samples for eight of the ten sensory attributes evaluated including off-dairy aroma, oxidized aroma, earthy aroma, barnyard aroma, fruity aroma-by-mouth, burnt sugar aroma-by-mouth, sweet aftertaste, and burnt sugar aftertaste. Descriptive analysis findings revealed differences between the two different sugar sources, but similarities between sugars from different brands from like sugar sources. Beet sugar samples were characterized by off-flavors including off-dairy, oxidized, earthy, and barnyard aromas and by a burnt sugar aroma-by-mouth and aftertaste, whereas cane sugar was associated with a fruity aroma-by-mouth and sweet aftertaste.

This research is of importance because it documents the differences between beet and cane sugar sources from a sensory perspective. Knowledge on sensory differences between the sugar sources will supplement the analytically determined volatile profile differences previously reported in the literature. Findings from this study provide insight to sugar manufacturers, in particular beet sugar manufacturers, by illustrating the importance of aroma in sugar. Deodorization strategies such as the use of odor scavenging packaging or additional sugar crystal washing steps should be studied in the future to provide recommendations to beet sugar manufacturers for product quality improvements.

The next step should focus on the impact of the sensory differences between beet and cane sugar sources in different product matrices, as sugar is mainly used as an ingredient. A difference test could be used to determine whether panelists can perceive a difference between various food products made with the two sugars from two different sources. A difference would suggest that additional factors, besides market price, be considered by food manufacturers when selecting the sugar source for their product.

3.6 Acknowledgments

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Table 3.1 Source, brand, manufacturer, distribution location, bag size, and lot number of sugar samples.

Source	Brand	Manufacturer	Location	Bag Size	Lot Number
Beet	Pioneer Sugar	Michigan Sugar Company	Bay City, MI	5lb	Y082C
Beet	United Sugar Corporation	United Sugar Corporation	Minneapolis, MN	50lb	K12307
Cane	C&H	ASR Group	Crockett, CA	4lb	52426 A2
Cane	United Sugar Corporation	United Sugar Corporation	Minneapolis, MN	50lb	F12323

Thank you for your interest in participating in this consumer testing study. To identify if you qualify for the study please provide answers to the following questions. If you have met qualifications for the study, you will be contacted with a testing schedule based on your listed availability. Your answers to these questions will be confidential and will be seen only by the researchers

Name: _____
Email Address: _____
Cell Phone Number: _____

1. **Do any of the following apply to you?**

   Follow a restricted diet for medical or personal reasons ☐ YES ☐ NO

   Diabetic ☐ YES ☐ NO

   Food or beverage allergies/sensitivities ☐ YES ☐ NO
   If so, please list the foods that you are allergic or sensitive to:

2. **Are you at least 18 years old?** ☐ YES ☐ NO

3. **You MUST be able to attend at least one 30 minute session on October 23, 28, 30 and November 4 and 6 OR October 24, 29, 31 and November 5 and 7. Check times <u>ALL</u> times that you are available for testing.**

	Monday	Tuesday	Wednesday	Thursday
9:00-9:30am	☐	☐	☐	☐
10:00-10:30am	☐	☐	☐	☐
11:00-11:30am	☐	☐	☐	☐
12:00-12:30pm	☐	☐	☐	☐
1:00-1:30pm	☐	☐	☐	☐
2:00-2:30pm	☐	☐	☐	☐
3:00-3:30pm	☐	☐	☐	☐
4:00-4:30pm	☐	☐	☐	☐
8:30-9:00am	☐	☐	☐	☐
9:30-10:00am	☐	☐	☐	☐
10:30-11:00am	☐	☐	☐	☐
11:30-12:00pm	☐	☐	☐	☐
12:30-1:00pm	☐	☐	☐	☐
1:30-2:00pm	☐	☐	☐	☐
2:30-3:00pm	☐	☐	☐	☐
3:30-4:00pm	☐	☐	☐	☐
4:30-5:00pm	☐	☐	☐	☐

Thank you for taking our survey! Your response is very important to us.

Figure 3.1 Screening survey used for panelist recruitment for the tetrad test.

Table 3.2 Descriptive attributes and references as generated by a trained descriptive panel evaluating beet and cane sugars. References used in final sample rating are indicated in bold.

Modality	Attribute	Definition	Reference Product	Reference Preparation
Aroma	**Off-dairy**	**Off-aroma associate with dairy**	**Powdered milk (Nestle; Solon, OH)**	**1/2 tsp in 2 oz. cup**
	Oxidized	**Aroma of wet cardboard**	**Wet cardboard**	**1/2 cm square in 5 oz. cup, dipped in water**
	Sugary	Aroma of sugar	Cotton candy	0.5 g in 2 oz. cup
	Heated sugar	Aroma of heat treated sugar	Toasted sugar	1 g sugar, heated for 5 min at 350 F, in 2 oz. cup
	Sugar cookie dough	Aroma of sugar	Sugar and butter creamed	1 g of creamed butter and sugar (2:3 ratio), in 2 oz. cup
	Earthy	Aroma of dirt	Potting soil	1/2 tsp in 2 oz. cup
	Earthy	**Aroma of root vegetable**	**Raw beet**	**1 g in 2 oz. cup**
	Barnyard	Aroma of barnyard	Hamster bedding	1/2 tsp in 2 oz. cup
	Barnyard	Aroma of barnyard	Wet hay	1 inch piece in 2 oz. cup
	Barnyard	**Aroma of barnyard**	**Goat milk (Mayenberg; Turlock, CA)**	**1/2 tsp in 2 oz. cup**
	Sulfurous	Aroma associated with sulfur	Hard-boiled egg yolk	1/5 yolk of hard-boiled egg, boiled 2 minutes, in 2 oz. cup
	Stinky feet	Aroma of stinky feet	Parmesan cheese	0.1 g in 5 oz. cup
	Stinky feet	Aroma of stinky feet	Swiss cheese	0.1 g in 5 oz. cup
	Stinky feet	Aroma of stinky feet	Limburger cheese	0.1 g in 5 oz. cup
	Nutty	Nutty aroma	Raw hazelnuts	3 pieces in 2 oz. cup
	Nutty	Nutty aroma	Toasted white bread	1/2 inch square of toast (3 min @ 350 F)
	Caramel	Aroma of caramel	Cowtail	1 inch piece in 2 oz. cup
	Caramel	Aroma of caramelized sugar	Light brown sugar	1 tsp in 2 oz. cup
	Caramel	Aroma of caramel	Baking caramel	1 square in 2 oz. cup
	Vanilla	Aroma of vanillin	Marshmallow	1 mini marshmallow in 2 oz. cup
	Vanilla	Aroma of vanillin	Dilute vanilla flavor	1 drop flavor in 100 mL water, 10 mL in 2 oz. cup
	Vanilla	**Aroma of vanillin**	**Vanilla powder (Sensient Flavors LLC; Indianapolis, IN)**	**Pinch of powder in 2 oz. cup**
	Vanilla	Aroma of vanillin	Dilute vanilla extract	10 mL of dilute vanilla solution (1:50 dilution) in 2 oz. cup

Table 3.2 (cont.)

Aroma-by-Mouth	Oxidized	Aroma-by-mouth of wet cardboard	Wet cardboard	1/2 cm square in 5 oz. cup, dipped in water
	Caramel	Aroma-by-mouth of dilute molasses	Dilute molasses	10 drops in 100 mL water, 10 mL in 2 oz. cup
	Fruity	**Fruity aroma-by-mouth**	**Dissolved cotton candy (Charms; Covington, TN)**	**2 g in 100 mL water, 10 mL in 2 oz. cup**
	Fruity	Fruity aroma-by-mouth	Smarties	6 smarties in 2 oz. cup
	Sugary	Aroma-by-mouth of sugar	Rock candy	1 g in 2 oz. cup
	Sugary	Aroma-by-mouth of sugar	Sugar in the raw	1 tsp in 2 oz. cup
	Sugary	Aroma-by-mouth of sugar	Karo light corn syrup	1 tbsp in 2 oz. cup
	Sugary	Aroma-by-mouth of sugar	Caster/baking sugar	1 tsp in 2 oz. cup
	Burnt sugar	**Aroma-by-mouth of burnt sugar**	**Dilute molasses (B&G Foods, Inc.; Roseland, NJ)**	**10 drops in 100 mL water, 10 mL in 2 oz. cup**
Taste	Sweet	Sweet taste	Saturated sugar solution	1 tbsp in 2 oz. cup
	Sweet	**Sweet taste**	**Half concentrated sugar solution (Domino Foods, Inc.; Yonkers, NY)**	**100mL sat. soln. with 100mL water, 1 tbsp in 2 oz. cup**
Aftertaste	Sweet	Sweet aftertaste	Saturated sugar solution	1 tbsp in 2 oz. cup
	Sweet	**Sweet aftertaste**	**Half concentrated sugar solution (Domino Foods, Inc.; Yonkers, NY)**	**100mL sat. soln. with 100mL water, 1 tbsp in 2 oz. cup**
	Burnt sugar	**Aftertaste of burnt sugar**	**Dilute molasses (B&G Foods, Inc.; Roseland, NJ)**	**10 drops in 100 mL water, 10 mL in 2 oz. cup**

Table 3.3 Descriptive attributes, definitions, reference product, and reference intensities as generated by a trained descriptive panel evaluating beet and cane sugar samples. Reference intensities were determined by panel average

Modality	Attribute	Definition	Reference Product	Reference Rating
Aroma	Off-dairy	Off-aroma associate with dairy	Powdered milk	**7.8**
	Oxidized	Aroma of wet cardboard	Wet cardboard	**13.6**
	Earthy	Aroma of root vegetable	Raw beet	**9.0**
	Barnyard	Aroma of barnyard	Goat milk	**13.1**
	Vanilla	Aroma of vanillin	Powdered vanilla flavor	**15.0**
Aroma-by-mouth	Fruity	Fruity aroma-by-mouth	Dissolved cotton candy	**9.9**
	Burnt sugar	Aroma-by-mouth of burnt sugar	Dilute molasses	**10.7**
Taste	Sweet	Sweet taste	Half concentrated solution	**12.6**
Aftertaste	Sweet	Sweet taste	Half concentrated solution	**9.9**
	Burnt sugar	Aftertaste of burnt sugar	Dilute molasses	**10.2**

Table 3.4 Tetrad results for beet and cane sugars by evaluation conditions: percent of correct responses, d', and binomial probabilities for sample differences.

Evaluation Condition	Modality	% Correct[a]	d'	p-value
With nose clips	Taste only	38	0.51	0.19
Without nose clips	Aroma only	75	1.89	0.00*
	Aroma and taste	61	1.40	0.00*

* indicates significance at $p<0.05$

[a] percent correct based on the total sample size of 100 panelists.

Table 3.5 Analysis of variance table for ten attributes describing four sugar samples.

Attribute	Judge	Sugar	Interaction (J*S)	Adjusted F-value
Aroma				
Off-Dairy	1.706	9.815***	2.202*	4.46*
Oxidized	5.767***	25.437***	3.878***	6.56*
Earthy	1.002	16.061***	2.145*	7.49**
Barnyard	2.287*	35.89***	2.699**	13.30**
Vanilla	4.891***	10.29***	3.752***	2.74
Aroma-by-Mouth				
Fruity	3.461**	21.499***	1.992*	10.79**
Burnt Sugar	3.272**	25.642***	1.693	
Taste				
Sweet	10.541***	5.054**	1.941*	2.60
Aftertaste				
Sweet	10.42***	4.637**	1.412	
Burnt Sugar	3.346**	30.472***	2.077*	14.67***

*, **, *** indicate significance at $p < 0.05$, $p < 0.01$, and $p< 0.001$, respectively

Table 3.6 Mean intensity ratings and Fisher's least significant difference (LSD) for significant attributes of four sugar samples rated by an 11-point scale from 0 to 10.

	Aroma				Aroma-by-Mouth		Aftertaste	
	Off-dairy	Oxidized	Earthy	Barnyard	Fruity	Burnt sugar	Sweet	Burnt sugar
United Sugar Corporation (Beet)	8.10^{c}	7.95^{c}	6.75^{b}	7.75^{d}	4.45^{ab}	6.35^{b}	6.45^{a}	6.30^{b}
Pioneer (Beet)	6.20^{b}	5.40^{b}	5.35^{b}	6.15^{c}	3.55^{a}	7.90^{c}	7.35^{ab}	7.40^{b}
C&H (Cane)	4.75^{a}	3.60^{a}	2.35^{a}	1.75^{a}	8.15^{c}	2.70^{a}	8.15^{b}	2.55^{a}
United Sugar Corporation (Cane)	5.00^{ab}	4.30^{a}	3.10^{a}	3.60^{b}	5.30^{b}	3.45^{a}	7.40^{b}	3.00^{a}

Means within a column that are noted with the same superscript letter indicate no significant difference ($p<0.05$) between sugar type for a given attribute.

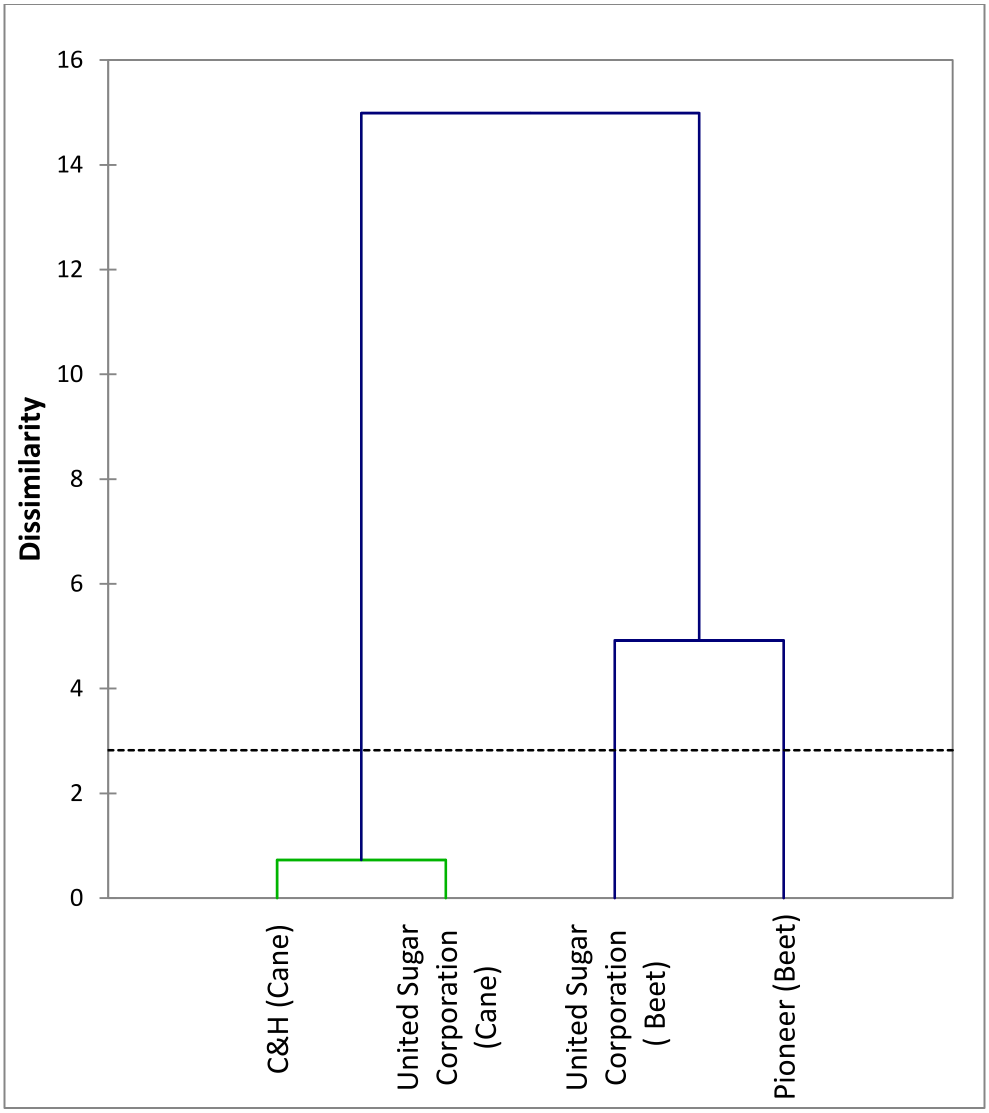

Figure 3.2 Dendrogram resulting from agglomerative hierarchical cluster analysis by Ward's method of four sugar types by intensity ratings for ten attributes on the dissimilarity scale.

Table 3.7 Pearson correlation matrix of descriptive analysis attributes from the descriptive analysis study.

Variables	**Off-dairy A**	**Oxidized A**	**Earthy A**	**Barnyard A**	**Fruity ABM**	**Burnt sugar ABM**	**Sweet AT**	**Burnt sugar AT**
Off-dairy A	1.000							
Oxidized A	**0.995**	1.000						
Earthy A	**0.967**	**0.958**	1.000					
Barnyard A	0.940	0.941	**0.990**	1.000				
Fruity ABM	-0.624	-0.638	-0.785	-0.853	1.000			
Burnt sugar ABM	0.700	0.667	0.853	0.860	-0.878	1.000		
Sweet AT	-0.921	**-0.953**	-0.903	-0.928	0.734	-0.614	1.000	
Burnt sugar AT	0.752	0.717	0.887	0.884	-0.853	**0.996**	-0.646	1.000

A=aroma, ABM=aroma-by-mouth, AT= aftertaste
Values in bold are different from 0 with a significance level alpha=0.05

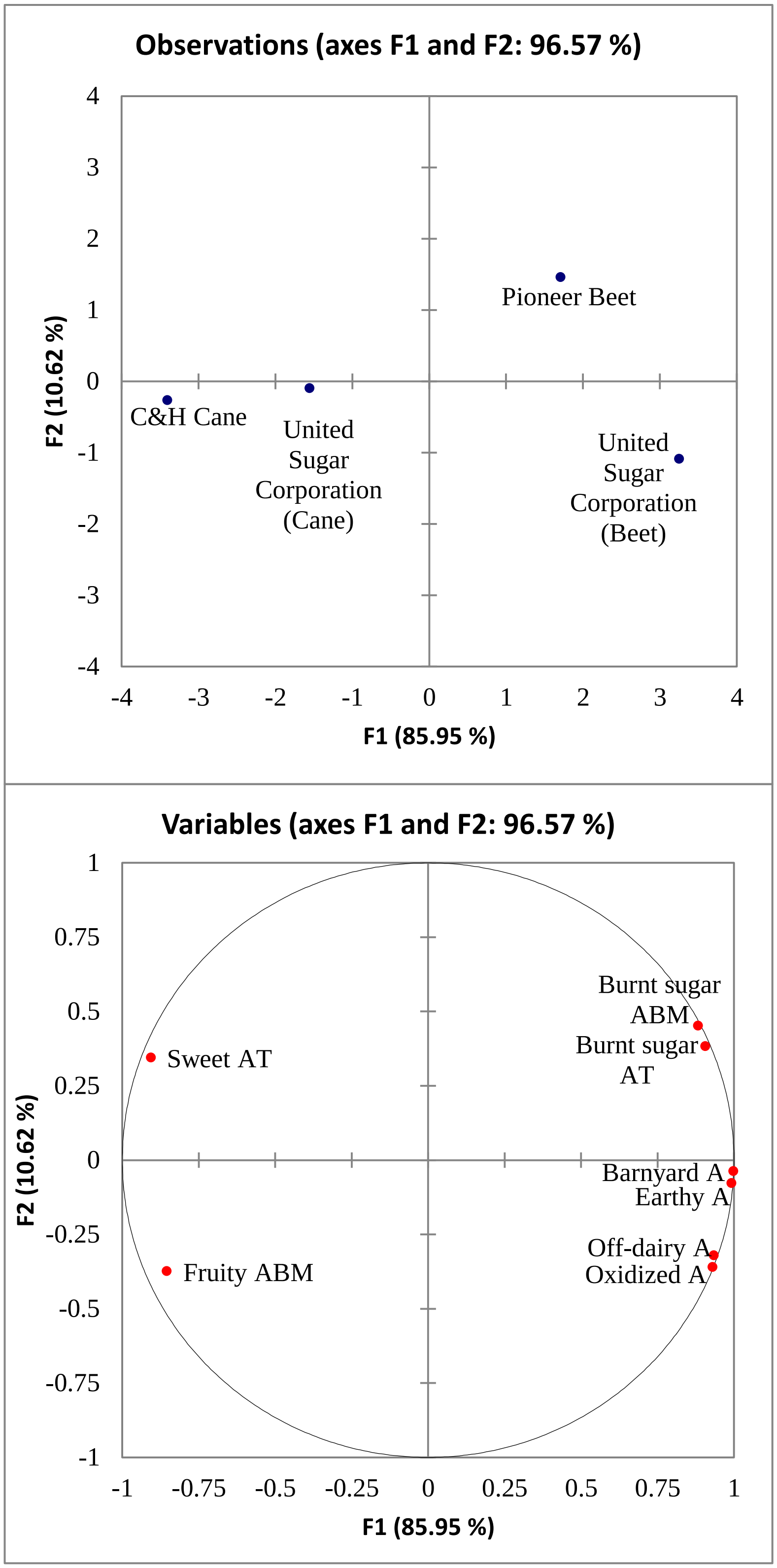

Figure 3.3 Principal component analysis plots of principal component 1 and 2 by the covariance matrix across four sugar types (top) for the mean intensity ratings for eight attributes (bottom).

A=aroma, ABM=aroma-by-mouth, AT= aftertaste

Chapter 4: Sensory difference between product matrices made with beet and cane sugar sources

4.1 Abstract

Sucrose, commonly termed sugar, is utilized for its sweetness and flavor and its effect on product functionality and characteristics. Commercially produced sucrose is primarily extracted from sugar beets or sugar cane. Chemically, beet and cane sugars are nearly identical, with both sources composed of greater than 99% sucrose. Though their chemical identities are comparable, differences in their analytically determined volatile profiles, thermal behaviors, and minor chemical compositions have been reported. However, scientific evidence characterizing the impact of these differences on product quality is lacking. The objective of this research was to determine whether panelists could identify a sensory difference between beet and cane sugars and product matrices made with beet and cane sugars. Sixty-two panelists used the R-index by ranking method to discern whether there was a difference between two brands of beet and two brands of cane sugars in regard to their aroma and flavor, along with a difference in pavlova, simple syrup, sugar cookies, pudding, whipped cream, and iced tea made with beet and cane sugars. R-index values and Friedman's rank sum tests showed differences ($p<0.05$) between beet and cane sugars in regard to their aroma and flavor. Significant differences between the sugar sources were also identified when incorporated into the pavlova and simple syrup. No difference was observed in the sugar cookies, pudding, whipped cream, and iced tea. Possible explanations for the lack of difference in these products include: 1) masking of beet and cane sensory differences by the flavor and complexity of the product matrix, 2) the relatively small quantity of sugar in these products, and 3) variation within these products being more influential than the sugar source. This research is significant because it identifies differences between beet and cane sugars and product matrices in which beet and cane sugars are not directly interchangeable.

4.2 Introduction

Sugar beet (*Beta vulgaris*) and sugar cane (*Saccharum officinarum*) are the primary sources of sucrose, commonly termed sugar. Sucrose is a product of photosynthesis (Colonna and others 2000). In the United States, the 2013/14 share of production forecast is 56.8% for beet sugar and 43.2% for cane sugar (SMD and USDA 2014).

Refined white beet and cane sugars are nearly chemically identical, with both sugars containing greater than 99% sucrose (Potter and Mansel 1992; Colonna and others 2000; Asadi 2005). The remainder of their composition consists of water, trace compounds from the sugar plant source, and compounds unintentionally incorporated during processing (Colonna and others 2000). Though their chemical identities are comparable, differences in their analytically determined volatile profiles, thermal behaviors, minor chemical compositions, and sensory properties have been reported (Monte and Maga 1982; Pihlsgard 1997; Asadi 2005; Godshall 2013; Lu and others 2013). The possible difference between beet and cane sugars has also been a point of discussion in many popular press sources, Internet articles, and blog posts (Ridge 2001).

The quality of sugar, and hence its value, is lessened by the presence of off-aromas. Beet sugar in particular often contains an off-aroma. A number of analytical flavor chemistry techniques have been used to study the volatiles responsible for this off-aroma. A combination of geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol) and fatty acids have been identified as key contributors (Marsili and others 1994; Godshall and others 1995; Moore and others 2004). Geosmin is an extremely potent odorant with an earthy and musty aroma, similar to the off-aroma perceived in beet sugar (Clarke and others 1995). Numerous volatile fatty acids, including acetic acid, butyric acid, isovaleric acid, and hexanoic acid, have been identified in beet sugar and are associated with sour, rancid, cheesy, sweaty, and fatty aromas (Moore and others 2004). Among the sources and causes of off-aromas are soil microorganisms, the beet root itself, and the breakdown of plant parts prior to processing (Marsili and others 1994; Godshall and others 1995; Clarke and others 1995; Lu and others 2003).

Upon a review of the literature, a wide variation in the melting temperature of sucrose was noted (Beckett and others 2006; Lee and others 2011). Further investigation revealed differences in the thermal behavior of beet versus cane sugars, which could contribute to explaining the variation in the literature reported melting temperatures. Differential Scanning Calorimetry (DSC) was used to study the thermal behavior of the sugar sources. In general, DSC thermograms for cane sugar samples exhibited two endothermic peaks, one small and one large; while beet sugar only exhibited one large endothermic peak (Lu and others 2013). The possible effect of this thermal behavior difference on product quality has not yet been studied.

Urbanus (2014 Chapter 3) has identified a sensory difference between beet and cane sugars and characterized this difference using descriptive analysis, though the impact of these differences in product matrices has not yet been explored. Employing sensory analysis testing to determine whether there is a difference between beet and cane sugars in various product matrices would serve to guide the research and development of sugar containing foods and beverages. Understanding sensory differences between beet and cane sugars in different product matrices is of value to the food industry since beet and cane sugars are often used interchangeably based on market price. In addition, a perceivable difference between products made with the two sugars may suggest a difference in the functionality of beet and cane sugars, which could then be used to optimize food and beverage formulations and processing parameters.

The R-index is derived from signal detection theory and measures the degree of difference from a conceptual standard (O'Mahony 1992). The R-index measure is based on a panelist’s ability to discriminate between a noise and signal (test) samples. The panelists rank the signal samples in terms of their similarity to the noise, ordering them from most similar to least similar compared to the noise. The degree of difference between the noise and each of the test samples is computed using an R-index analysis. A greater degree of difference indicates a greater probability of panelists being able to distinguish a difference between the samples (O'Mahony 1992; Lee and others 2007). R-index by ranking test methodology is superior to general difference tests because it allows multiple comparisons to be made at once rather than comparing one pair of samples at a time. For that reason, a ranking test can provide the degree of difference among samples in a single session. Besides needing more testing sessions to obtain equivalent data, general difference tests have a lower power and therefore require more participants (O'Mahony 1992). The R-index by ranking method has been successfully used to determine differences in a number of products, such as peaches (O'Mahony and others 1983), toothpaste (Lee and O'Mahony 2005), and milk-beverages (Villegas and others 2007) and was therefore employed herein.

The objective of this research was to determine whether panelists could identify a sensory difference between beet and cane sugars and product matrices made with beet and cane sugars using the R-index by ranking method. Due to preliminary findings, it was hypothesized that a panelist's ability to distinguish between beet and cane sugars in a product is product dependent.

4.3 Materials and Methods

Sucrose

Two brands of beet sugar, Pioneer Sugar and United Sugar Corporation, and two brands of cane sugar, C&H and United Sugar Corporation, were selected in order to have representative beet and cane samples from different manufacturers (Table 4.1). United Sugar Corporation donated beet and cane sugars and the Pioneer Sugar and the C&H were purchased from a local grocery store (Urbana, IL).

C&H sugar was designated as the noise by the researcher. Previous studies have identified off-aromas associated with beet sugar (Monte and Maga 1982; Marsili and others 1994; Godshall and others 1995; Pihlsgard 1997; Moore and others 2003; Moore and others 2004). Therefore, a cane sugar was chosen for the noise because it was considered more neutral. C&H sugar was chosen specifically because it is a well-recognized brand and is commercially available to consumers.

Panelists

Sixty-two panelists (47F and 15M, age range 18-35 yrs) participated in this study. Panelists were recruited through a departmental e-mail listserv and by flyers posted in campus buildings. The panelists were selected based on interest and availability. All panelists were compensated at the completion of the study.

Sugar Sample Preparation

Aroma: Sniff bottles (125 mL Nalgene PTFE wash bottles, Fisher, Pittsburgh, PA) were thoroughly rinsed in odor free purified water so that no residual odors were detectable in the bottles. Each bottle was filled with fifty grams of sugar. The panelists were instructed to gently squeeze the bottle and sniff the aroma emitted from each sniff bottle.

Flavor: In this study, flavor was defined as the sensory experience involving aroma and taste perceptions. Plastic 29.57 mL cups with lids (Solo Cup Company, Inc., Chicago, IL), labeled with a randomized three-digit code, were filled with approximately one gram of sugar. The panelist was instructed to taste the entire contents of the cup at once for each sample.

Product Selection and Preparation

The products selected for the difference test were chosen to exemplify the diverse functionality of sugar, in addition to sweet taste. Caramelization is a browning reaction that occurs when sucrose (or other simple carbohydrate) is heated at a specific temperature for a length of time (Lee and others 2011; Schmidt 2012). This reaction leads to flavor development and surface browning in various products (Monte and Maga 1982; Davis 1995). Sugar also plays a role in creaming by incorporating air into the shortening during mixing. By doing so, the sugar aids in achieving a light texture in the product (Paton and others 1981; Wilderjans and others 2013). The foam stability properties of sugar are important as well. Sugar works as a whipping aid to stabilize beaten foams by interacting with the protein (Lomakina and Mikova 2006; Foegeding and others 2006; Raikos and others 2007). Sugar influences gelatinization by competing with starch for available water, which serves to delay the onset of gelatinization (Hester and others 1956; Spies and Hoseney 1982). Sugar is also effective in delaying gluten development by competing with gluten-forming proteins for water. This inhibits the proteins from fully hydrating and results in a less rigid dough (Pareyt and others 2009). The viscosity and texture of many food products are dependent on sucrose. The functionality of sugar in each of the products tested herein are presented in Table 4.2. The products have also been categorized into heat and no heat applications and further subdivided by phase (liquid, semi-solid, solid) in Table 4.3.

A protocol was established for the preparation of each product in the test design. Two batches of product were made with each of the four sugars and, because the test design required twice the amount of noise samples, an additional double batch was made for the noise. Thus, the noise batch required slightly larger equipment and longer processing times. All batches of a product were prepared on the same day, the day prior to testing, to ensure consistency. Before preparation, each ingredient was preweighed and placed in a sealed container with a label indicating the ingredient and batch number. Experienced bakers prepared the products using the preweighed ingredients and established protocol. The bakers were familiar with the protocols, but were unaware of what ingredient in the formulation was changing from batch to batch. This eliminated experimental bias. The bakers also completed a series of qualitative questions pertaining to each batch that they prepared. This allowed the researchers to gather unbiased observational data of product preparation and baking. However, no consistent differences were identified based on these observations. After preparation, products were placed in plastic cups with lids (Solo Cup Company, Inc., Chicago, IL) and labeled with a randomized three-digit code. Each batch corresponded to a different code.

Pavlova: The test and noise batches of pavlova were prepared using the protocol outlined in Figure 4.1 with preweighed ingredients (Table 4.4). Egg white powder and sugar were combined in the Hobart KitchenAid K45SS Tilt Stand Mixer (KitchenAid, St. Joseph, MI) with the metal whisk attachment on speed two for 30 seconds. Water was added and the ingredients were mixed for an additional two minutes on speed four. The bowl was scraped before mixing again for two minutes at speed four. While continuing to mix for an additional 30 seconds, the sugar was gradually added. The mixer was, then, stopped and the sides were scrapped down. Next, the mixer was turned to speed eight for 7.5 minutes, stopping at four minutes to scrape down the bowl. The resultant meringue was placed in a pastry bag (Wilton, Woodridge, IL) and manually dispensed onto a baking sheet lined with parchment paper. The diameter of each pavlova prior to baking was approximately 2.54 cm. The pavlova were baked in the Garland

Master 200 Convection Oven (Garland, Mississauga ON, Canada) at 149°C for 22 minutes. Pavlova were removed from the oven, cooled and then placed in labeled plastic 59.2 mL cups with lids (Solo Cup Company, Inc., Chicago, IL). The noise batch followed the same protocol as the test batches with the following changes; a Berkel BX20 20 quart mixer (ITW Food Equipment Group LLC, Glenview, IL) was used to prepare the batter, the egg white powder and sugar were mixed at speed one, water was added and mixed on speed one for three minutes, after scraping down the bowl, the batter continued to mix on speed one for two minutes, the sugar was added over a 30 second time period on speed one, the mixer was turned up to speed three for 10 minutes stopping to scrape the sides of the bowl halfway through.

Simple syrup: The test and noise batches of simple syrup were prepared using the protocol outlined in Figure 4.2 with preweighed ingredients (Table 4.5). Water and sugar were combined in a stainless saucepan and stirred over high heat on an American Range stove top (Dvorson's Food Service Equipment, Inc., Sausalito, CA). The solution was brought to a boil. After 14 minutes on the stove, the syrup was removed from the heat and cooled to room temperature before dispensing into labeled plastic 29.5 mL cups with lids (Solo Cup Company, Inc., Chicago, IL). The noise batch followed the same protocol as the test batches although the solution required 16 minutes on the heat instead of 14 due to the larger batch size.

Sugar cookies: The test and noise batches of sugar cookies were prepared using the protocol outlined in Figure 4.3 with preweighed ingredients (Table 4.6). The shortening and sugar were creamed together in a Hobart KitchenAid K45SS Tilt Stand Mixer (KitchenAid, St. Joseph, MI) with a flat beater paddle at speed two for 30 seconds, after which, the bowl was scraped down. The mixer was turned to a speed of one and eggs were incorporated into the batter over a 30 second time period. Milk and vanilla were added and the dough continued to mix for another 25 seconds. All-purpose flour, baking powder and salt were sifted and added slowly to the mixer over one minute and 45 seconds. Once all ingredients were incorporated, the mixing speed was increased to two for 10 seconds. The dough was wrapped in plastic wrap and refrigerated for one hour. The refrigerated dough was, then, scooped (~8g scoops) and baked on a parchment sheet lined pan at 177^oC in a Garland Master 200 Convection Oven (Garland, Mississauga ON, Canada) for six minutes. Baked cookies were removed from the oven, cooled and then placed in labeled plastic 59.2 mL cups with lids (Solo Cup Company, Inc., Chicago, IL). The noise batch followed the same protocol as the test batches with the following changes; a Berkel BX20 20 quart mixer (ITW Food Equipment Group LLC, Glenview, IL) was used to prepare the dough, the shortening and sugar were mixed at speed one for 45 seconds, the egg was added at speed one for 45 seconds, the milk and vanilla were added at speed one for 50 seconds, the dry ingredients were added at speed one over a 60 second time period and then the mixer was increased to speed two for 15 seconds.

Pudding: The test and noise batches of pudding were prepared using the protocol outlined in Figure 4.4 with preweighed ingredients (Table 4.7). Sugar, egg yolks, 2% milk, and cornstarch were combined with a whisk in a medium sized bowl for 30 seconds and then set aside. Heavy cream and the remaining milk were combined in a stainless saucepan and stirred over low heat on an American Range stove top (Dvorson's Food Service Equipment, Inc., Sausalito, CA) for 16 minutes. The pot was removed from the heat after 16 minutes and six, 118.3 mL ladles of the milk and cream were slowly added to the egg mixture while whisking continuously for 20 seconds. Once combined, the mixture was returned to the pot and brought to a boil on medium heat. After five minutes of heating, the pot was removed from the heat and vanilla was stirred in until well combined for 30 seconds. The pudding was covered and placed in the refrigerator to cool for 30 minutes before being distributed into labeled plastic 59.2 mL cups with lids (Solo Cup Company, Inc., Chicago, IL). All samples were stored in the refrigerator and taken out 20 minutes prior to the start of each testing session. Panelists were instructed to stir each sample with a plastic spoon 20 times in a gentle circular motion before tasting. The noise batch followed the same protocol as the test batch with the following noted changes; the sugar, egg yolks and cornstarch were whisked for 45 seconds, the heavy cream and milk were heated for 19 minutes, 12 ladles of milk and cream were added to the egg mixture over a 40 second time period, once returned to the pot, the mixture took nine minutes to reach the kerplop stage, and the pudding took 60 minutes to cool in the refrigerator.

Whipped cream: The test and noise batches of whipped cream were prepared using the protocol outlined in Figure 4.5 with preweighed ingredients (Table 4.8). Prior to preparation, the Hobart KitchenAid K45SS Tilt Stand Mixer (KitchenAid, St. Joseph, MI) bowl and metal whisk attachment were chilled in the freezer for 15 minutes. The whipping cream was then added to the bowl and mixed at speed six for four minutes at which point a soft peak was reached. Sugar was slowly added to the cream over a 30 second period, while the mixer continued running at speed six. After 30 seconds the bowl was scraped down and then the mixer was turned to speed six for an additional minute. The mixer was then stopped and the cream was folded with a spatula and then mixed on speed six for 30 more seconds. The whipped cream was then distributed into labeled plastic 59.2 mL cups with lids (Solo Cup Company, Inc., Chicago, IL) and refrigerated. Samples were taken from the refrigerator 20 minutes prior to the start of each testing session. Panelists were instructed to stir each sample with a plastic spoon 10 times in a gentle circular motion before tasting to ensure product homogeneity. The noise sample followed the same protocol as the test batches with the following changes; a Berkel BX20 20 quart mixer (ITW Food Equipment Group LLC, Glenview, IL) was used, the whipping cream was mixed at speed three for two minutes, after the sugar was incorporated, the mixture was stirred at speed three for one minute, the final mixing step was eliminated.

Iced tea: The test and noise batches of iced tea were prepared using the protocol outline in Figure 4.6 with preweighed ingredients (Table 4.9). Iced tea powder, sugar and water were combined in a pitcher and mixed with a wooden spoon for one minute. The prepared iced tea was poured into labeled plastic 59.2 mL cups with lids (Solo Cup Company, Inc., Chicago, IL) and placed in the refrigerator. The samples were pulled from the refrigerator 30 minutes prior to the start of the testing session. The noise batch followed the same protocol as the test batches, but the mixture was stirred for 1.5 minutes due to the larger batch size.

<u>Sugar Content Determination</u>

The amount of sugar on a percent weight by weight basis was calculated for each product. For products that involved heat, the sugar content was calculated based on the difference in product weight before and after the application of heat. The sugar content for products that did not involve heat during processing was calculated using the weight of the ingredients in the product formula.

Test Design

The difference test took place in a room with partitioned booths maintained 22^{o}C and 33% relative humidity. Panelists evaluated the samples under incandescent lighting. The data were gathered using the Compusense *five* Plus (Version 5.0: Guelph ON, Canada) data acquisition system.

Panelists utilized a R-index by ranking method in this study. Data for a single product (sugar aroma, sugar flavor, simple syrup, pudding, sugar cookie, pavlova, iced tea, whipped cream) was obtained from one day of testing, for a total of eight sessions, lasting 15 to 20 minutes each. During each session, panelists evaluated 10 samples. The samples were presented to the panelists on two trays with five samples on each tray. Each tray consisted of one noise sample and four test samples. All panelists evaluated the same samples on the same days; however, the samples were randomized per panelist. The order of the randomized design was determined by the Compusense *five* Plus (Version 5.0: Guelph ON, Canada) data acquisition system.

Each subject was served their first tray of samples along with warm and room temperature rinse water. The subjects were asked to rinse with warm (26-29^{o}C) and room temperature spring water (Absopure, Urbana, IL) before the first sample and between subsequent samples. Panelists were instructed to evaluate each sample in the order presented and rank them in order from “1” to “4”, with “1” being the most similar to the noise and “4” being least similar. After the panelists finished evaluating the first set of samples (replication 1), there was a three minute break before they were served their second set of samples (replication 2). The panelists repeated the same procedure with the second set of samples.

The first session included brief training followed by the first product testing. The training was intended to familiarize the panelists with the methodology. Panelists ranked salt solutions by how similar they were to the salt solution in the cup labeled 'Noise.' Instructions were both verbal and written for the training session.

Data Analysis

The raw data were collected using Compusense *five* Plus (Version 5.0: Guelph ON, Canada) and analyzed with Microsoft Excel. A response matrix was constructed for each product that was tested in order to calculate the R-index measure. The data were converted to R-index scores using O'Mahony's method (1992). An example of how the data were converted to R-index scores for each product tested is shown in Figure 4.7. The number of times each sample (United Sugar Corporation cane, United Sugar Corporation beet, Pioneer (beet), C&H) was placed at each rank was totaled across the panelists for each product that was tested. The rank order was then converted to signal sure (SS), signal unsure (S?), noise unsure (N?), and noise sure (NS). The R-index measure was calculated for each sample by designating C&H as the noise (control) and using O'Mahony's R-index equation (1992). R-index values were calculated for each replication and by combining replications for each product. The calculated R-index values were compared to the critical value (n=62 or n=124) for two-tailed test at α=0.05 to determine if differences were significant (Bi and O'Mahony 1995; Bi and O'Mahony 2007). The comparisons between the test samples were all relative to the same noise, assuming the noise to have an R-index of 50%. An R-index value of 50% indicates parity with the noise sample. Perfect discrimination between the test and noise sample would result in an R-index of 100%. A value between 50% and 100% signifies partial discrimination; the higher the value, the greater the degree of discrimination between the samples. An R-index value between 0% and 50% signifies that the panelists identified this sample as being confusable, yet different from the noise sample.

In addition, data were analyzed by Friedman test of ranked sums analysis with multiple comparison procedure of least significant ranked difference (LSRD) to determine if the samples differ significantly from one another. This method enabled all pairs of samples tested to be compared. The analysis is useful in that it determines the significance of the rankings, although it cannot be used to determine the degree of difference between samples (Freund and others 2010).

To compare replications, the magnitudes of difference between the R-index values from each replication were calculated.

4.4 Results and Discussion

The overall R-index values calculated from combining the ranking data from both replications are given in Table 4.10. The R-index values are compared to the critical value for significance at $p<0.05$, which is 50 ± 7.108%. The R-index values calculated are given in Table 4.11. The R-index values are compared to the critical value for significance at $p<0.05$, which is 50 ± 9.948%. Data suggest that panelists could discriminate between beet and cane sugars in the aroma and flavor of sugar and when the sugars were incorporated into simple syrup and pavlova.

R-index values also indicate that panelists confused the products made with United Sugar Corporation beet, Pioneer, or United Sugar Corporation cane sugars and the products made with C&H sugar when comparing it to the noise (products made with C&H sugar) for the sugar cookie and whipped cream. This indicates that the panelists were able to discern a difference between the signal and noise sample, but they reversed the labeling of the stimuli, such that the noise was referred to as signal and vice versa.

The results from the least significant ranked difference (LSRD) analysis, given in Table 4.12 for combined replications and Table 4.13 for individual replications, are in agreement with the computed R-index data. The analysis was performed by combining replications for each product. Subscripts indicate differences identified by panelists amongst the samples. Again, this analysis suggests that there is a significant difference ($p<0.05$) in the aroma and flavor of the sugar samples and between beet and cane sugars in the pavlova and simple syrup. Both types of data analysis, R-index and LSRD, suggest that panelists could not differentiate the beet and cane sugars in the sugar cookies, pudding, whipped cream, and iced tea.

The difference in aroma and flavor between beet and cane sugars can be attributed to their volatile profiles. Previous studies have utilized analytical flavor chemistry techniques to identify a malodor in beet sugar caused by a combination of geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol) and volatile fatty acids (Marsili and others 1994; Godshall and others 1995; Moore and others 2004). The geosmin and fatty acids that are responsible for the characteristic malodor have been associated with the soil microorganisms, the beet root itself, and the breakdown of the root, beet tops, and leaves of the sugar beet (Marsili and others 1994; Godshall and others 1995; Clarke and others 1995; Lu and others 2003). These compounds contribute an earthy, musty aroma to the beet sugar, which allow panelists to discern a difference between beet and cane sugars (Clarke and others 1995; Moore and others 2004). Findings from Urbanus (2014 Chapter 3) also support the presence of these off-aromas in beet sugar.

The data from this study can also be used to assess whether there is a perceivable difference between the four different brands of sugar used in the study. Each brand can be compared to one another using the LSRD values in Table 4.12. For the sugar evaluated by aroma and flavor, as well as the pavlova and simply syrup, panelists generally could differentiate the sugar from the two sources but could not differentiate between different brands of sugar from like sugar sources. This suggests that there is a larger difference between sugar sources than between brands of like sugar sources. In the remainder of the products tested, panelists typically could not differentiate between any of the brands of sugar. The sugars were not differentiable in these products due to the flavor and/or complexity of the product matrix and the quantity of sugar in the product.

The flavor and/or complexity of the product matrix and the amount of sugar may be important factors when distinguishing between beet and cane sugars in products. The data suggest that panelists can perceive the difference between beet and cane sugars when incorporated into the pavlova and simple syrup. Of the products tested, the pavlova and the simple syrup had the most simple flavor profiles and also contained the most sugar with 52.6% and 86.0% (w/w), respectively (Table 4.14).

Table 4.15 shows the magnitude of difference between replications for each product. A larger variation between replications was observed in the pavlova, simple syrup, sugar cookies, pudding, whipped cream, and iced tea compared to the sugar aroma and sugar flavor. For the most part, both replications resulted in the same conclusions for the pavlova, simple syrup, and pudding despite the large magnitude of difference indicating that variation may have less influential in these products Table 4.11. Overall, variation may be due to a number of factors, including panelist performance, processing operations, and environmental conditions. Additional panel training or replications may have helped to minimize variation due to panelists. Environmental conditions such as temperature and humidity often fluctuate from day to day and affect the products themselves. Despite the meticulous protocol established for each product, differences due to processing operations, such as non-uniformity in oven air flow and temperature may result in unavoidable variation. The significant variation that exists in many of the products may be more influential than the difference between the sugars in these specific products.

It is important to note that a difference in the texture of the pavlova made with the beet and cane sugars was observed by the researchers. After baking, the pavlova made with beet sugar was notably softer (marshmallow-like) in texture compared to the desirable texture of those made with cane sugar (crunchy, hard, foam-like). This was consistent across the replications. Since difference tests are used to identify the nature of the difference between samples, this observation may not be the reason for the difference in the pavlova identified by the panelists, but is worthy of further investigation. To determine if the pavlova made with beet sugar could achieve the same texture as the cane-made samples, a preliminary test was conducted. By extending the baking time from 22 to 38 minutes, the pavlova made with beet sugar was able to reach the same texture as the cane-made samples. Further texture testing is necessary in order to quantify these findings and determine their cause. It is possible that the two sugar sources may function differently in stabilizing the egg foam or that the difference in texture between the pavlova is a reflection of differences in the thermal properties of beet and cane sugar sources (Lu and others 2013).

4.5 Conclusion

Though beet and cane sugars are nearly chemically identical, they can be distinguished from each other and when incorporated into some products. The aroma and flavor of beet and cane sugars were significantly different. This difference can be attributed to the geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol) and volatile fatty acids present in beet sugar. Combined, these compounds have an earth, musty aroma, identical to the off-aroma perceived in beet sugar.

In addition, data from this study indicated a significant difference between beet and cane sugars in some of the product matrices. The ability to perceive differences between beet and cane sugars in different product matrices may be influenced by the flavor and/or complexity of the product matrix, the quantity of sugar in the formulation, and the differences in the thermal behaviors of beet and cane sugars. Variability due to panelist performance or processing is another factor that may impact the ability the discriminate between beet and cane sugars in a product. Food manufacturers should consider the sugar source selection when formulating a product with sugar. The impact of matrix and flavor complexity, sugar quantity, and differences in the thermal behaviors of the sugars on a consumer's ability to differentiate between beet and cane sugars should be examined in future studies.

Future research should further explore the nature of the difference that was identified in the simple syrup and pavlova made with beet and cane sugars using descriptive analysis. Additional research is also needed to investigate the cause of the observed texture difference in the pavlova made with beet compared to cane sugar. Additionally, another difference test can be performed using different products to provide more insight on product matrices where beet and cane sugars are not interchangeable.

Findings from the current study elucidate the differences between beet and cane sugars and point to the off-aroma in beet sugar as the cause of this difference. It is possible that the off-aroma in beet sugar will generate expectations on the acceptability of a product made with beet sugar. Therefore, another avenue for future work is to examine whether psychological influences drive perceived differences in liking of a product made with beet sugar versus a product made with cane sugar.

4.6 Acknowledgments

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Table 16--U.S. beet and cane sugar production (including Puerto Rico), by fiscal year and share of total [Internet]. : National Agricultural Statistics Service and Sweetener Market Data (SMD), Farm Service Agency, USDA; 2014 [Accessed 2014 2/28]. Available from: http://www.ers.usda.gov/

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Table 4.1 Source, brand, manufacturer, distribution location, bag size, and lot number of sugar samples.

Source	Brand	Manufacturer	Location	Bag Size	Lot Number
Beet	Pioneer Sugar	Michigan Sugar Company	Bay City, MI	5lb	Y082C
Beet	United Sugar Corporation	United Sugar Corporation	Minneapolis, MN	50lb	K12307
Cane	C&H	ASR Group	Crockett, CA	4lb	52426 A2
Cane	United Sugar Corporation	United Sugar Corporation	Minneapolis, MN	50lb	F12323

Table 4.2 Functionality of sugar in the products selected for sensory testing.

	Caramelization	Creaming	Foam Stability	Gelatinization	Gluten Development	Viscosity
Pavlova			x			
Simple Syrup	x					x
Sugar Cookies	x	x			x	
Pudding	x			x		
Whipped Cream			x			x
Iced Tea						x

Table 4.3 Product matrix divided by heat and no heat and phase.

<table>
<tr><th></th><th>Heat</th><th>No Heat</th></tr>
<tr><td>Liquid</td><td>Simple syrup</td><td>Nestea iced tea</td></tr>
<tr><td>Semi Solid</td><td>Pudding</td><td>Whipped cream</td></tr>
<tr><td rowspan="2">Solid</td><td>Sugar cookie</td><td rowspan="2">Commercialized sugar (nasal and retronasal)</td></tr>
<tr><td>Pavlova</td></tr>
</table>

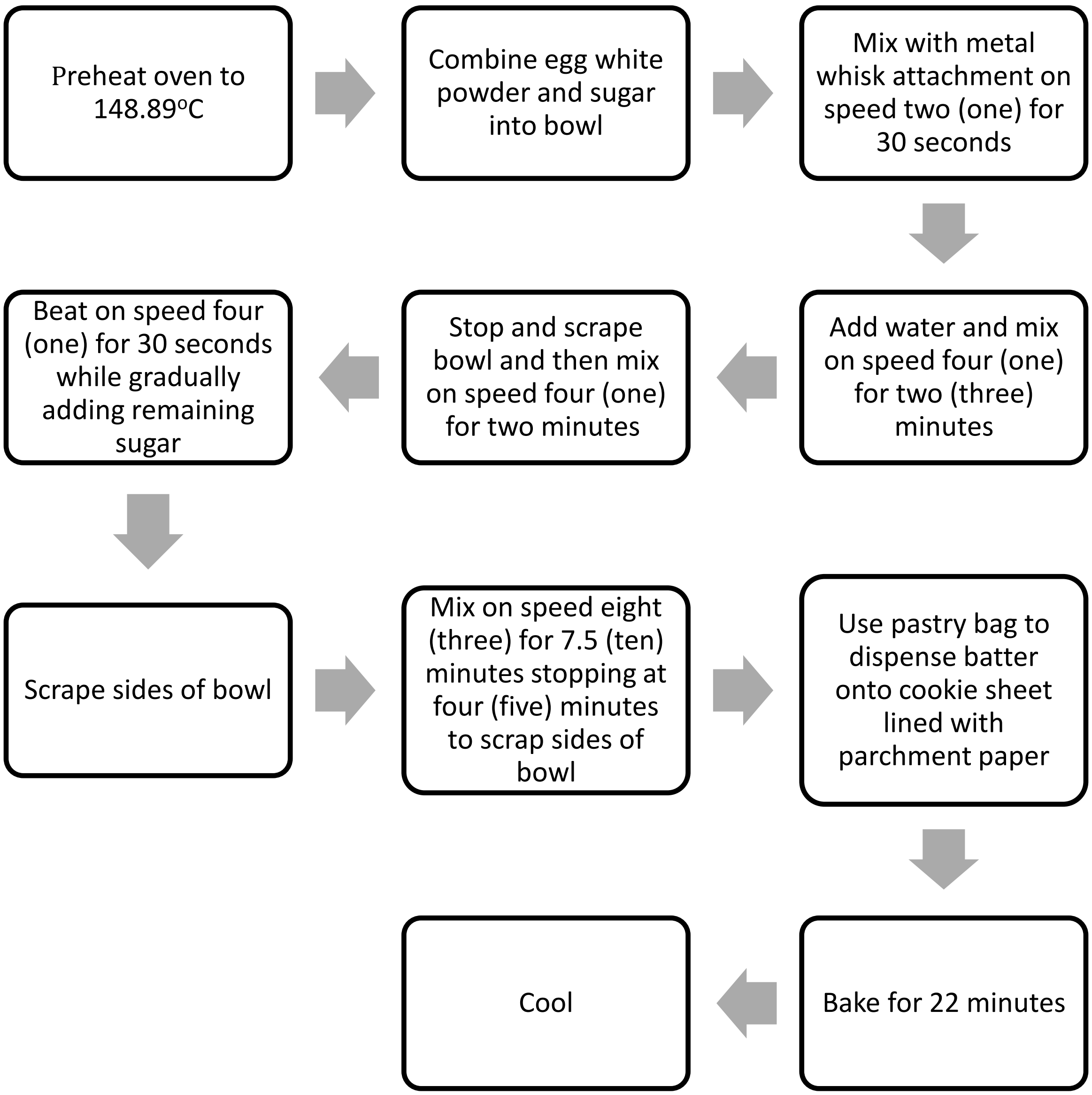

Figure 4.1 Protocol for pavlova test and noise sample preparation. If different than test sample, noise values are given in parenthesis.

Table 4.4 Pavlova formulation.

Ingredient	**% w/w**
Sugar	48.4
Water (Absopure; Urbana, IL)	45.9
Egg white powder (Deb el Just White; Elizabeth, NJ)	5.7

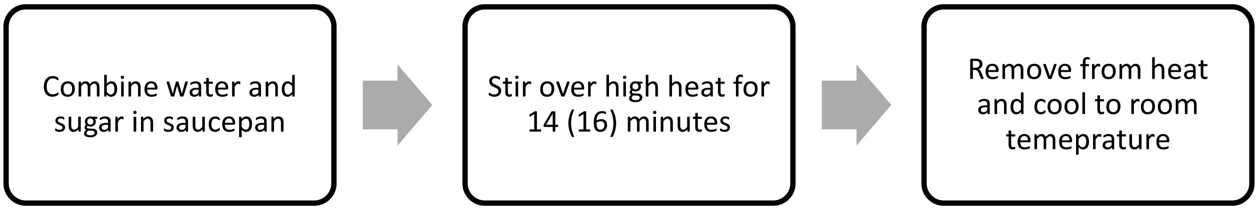

Figure 4.2 Protocol for simple syrup test and noise sample preparation. If different than test sample, noise values are given in parenthesis.

Table 4.5 Simple syrup formulation.

Ingredient	% w/w
Sugar	50
Water (Absopure; Urbana, IL)	50

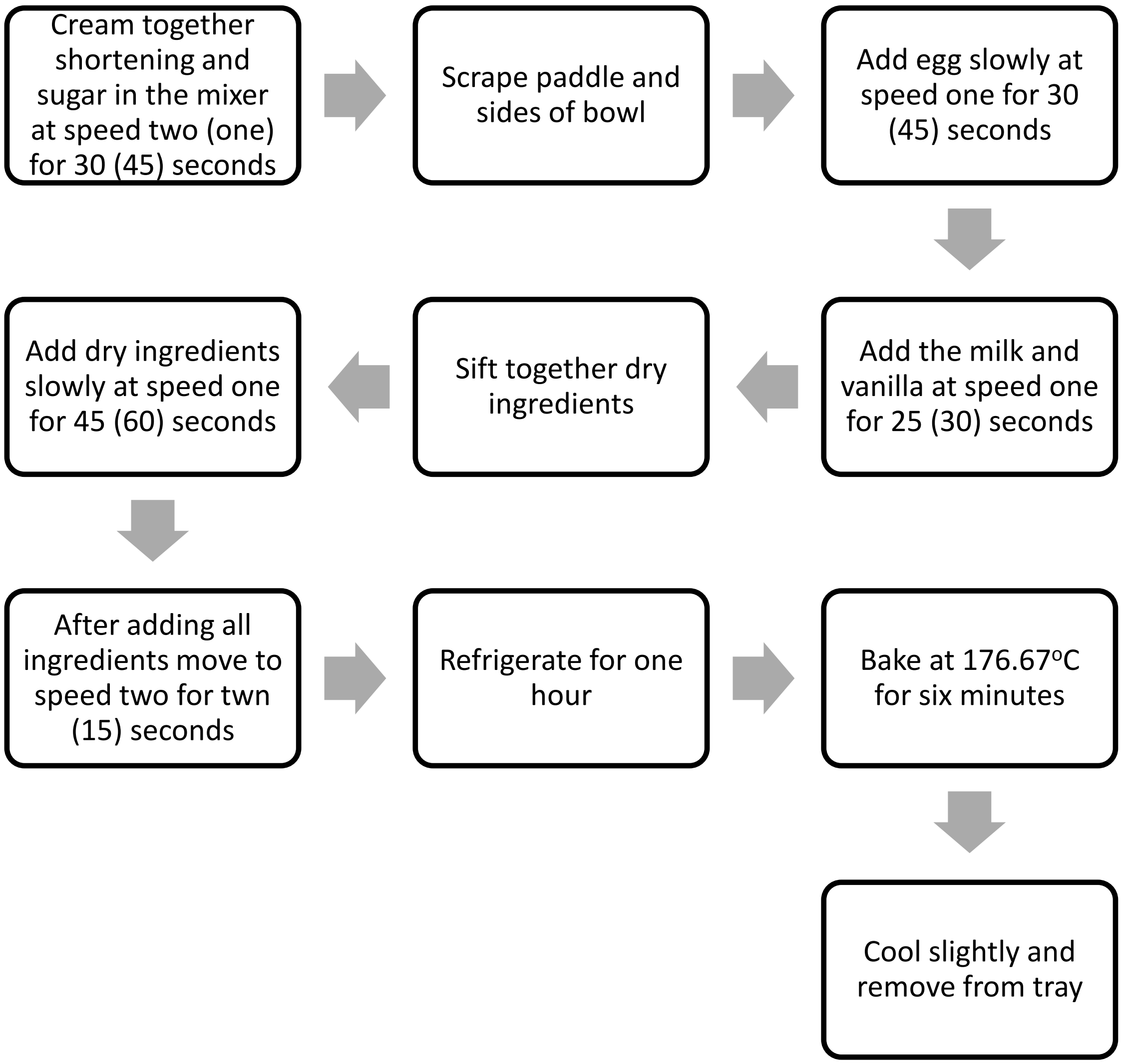

Figure 4.3 Protocol for sugar cookie test and noise sample preparation. If different than test sample, noise values are given in parenthesis.

Table 4.6 Sugar cookie formulation.

Ingredient	% w/w
All-purpose flour (Gold Medal; Minneapolis, MN)	45.8
Sugar	26.9
All-purpose shortening (Crisco; Orville, OH)	15.8
Liquid egg (Schnucks; St. Louis, MO)	7.1
2% milk (Prairie Farms; Carlinville, IL)	2.8
Baking powder (Clabber Girl; Terre Haute, IN)	1.2
Vanilla extract (McCormick; Hunt Valley, MD)	0.2
Iodine salt (Great Value; Bentonville, AR)	0.2

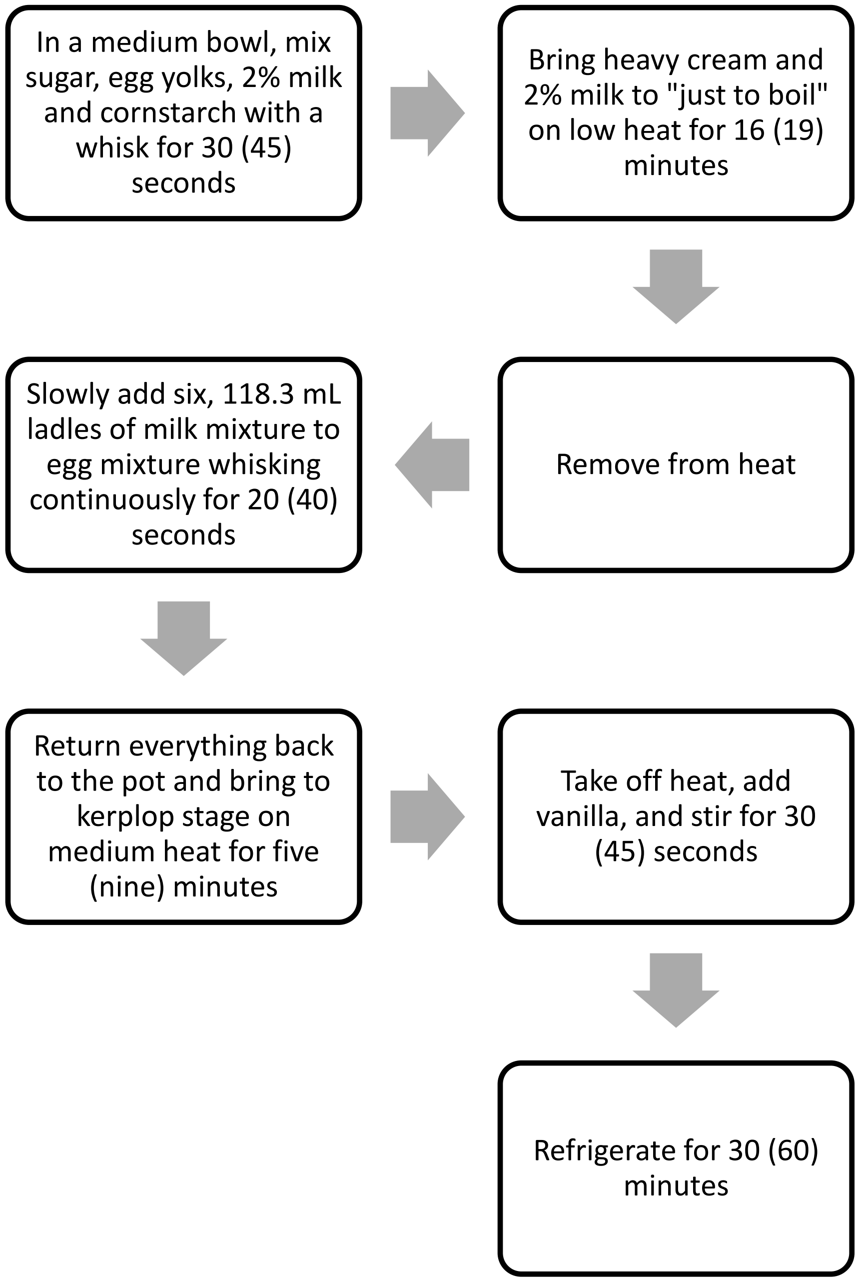

Figure 4.4 Protocol for pudding test and noise sample preparation. If different than test sample, noise values are given in parenthesis.

Table 4.7 Pudding formulation.

Ingredient	% w/w
2% milk (2) (Prairie Farms; Carlinville, IL)	48.8
Sugar	16.9
2% milk (1) (Prairie Farms; Carlinville, IL)	12.5
Heavy whipping cream (Prairie Farms; Carlinville, IL)	11.4
Cornstarch (Argo; Summit, IL)	5.6
Egg yolks (Schnucks; St. Louis, MO)	4.6
Vanilla extract (McCormick; Hunt Valley, MD)	0.1

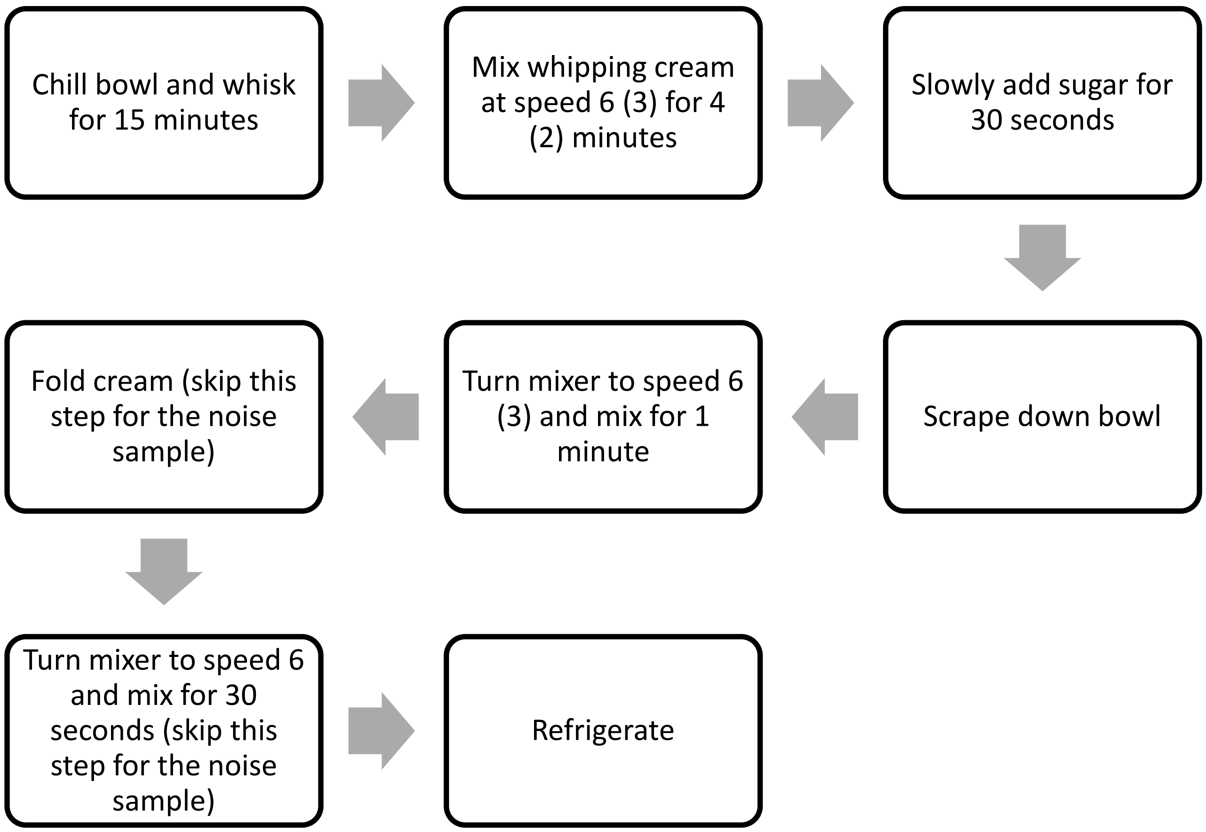

Figure 4.5 Protocol for whipped cream test and noise sample preparation. If different than test sample, noise values are given in parenthesis.

Table 4.8 Whipped cream formulation.

Ingredient	**% w/w**
Whipping cream (Prairie Farms; Carlinville, IL)	75.9
Sugar	24.1

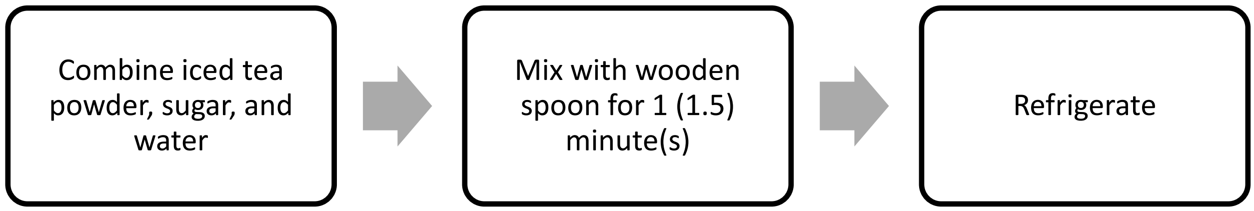

Figure 4.6 Protocol for iced tea test and noise sample preparation. If different than test sample, noise values are given in parenthesis.

Table 4.9 Iced tea formulation.

Ingredient	**% w/w**
Water (Absopure; Urbana, IL)	91.4
Sugar	7.9
Nestea Unsweetened Iced Tea Mix (Glendale, CA)	0.7

Sample Presented	Rank order 1	2	3	4
United Cane	24	33	4	1
C&H	34	22	3	3
United Beet	2	1	19	40
Pioneer	2	6	36	18

Sample Presented	SS	S?	N?	NS
United Cane	1	4	33	24
C&H	3	3	22	34
United Beet	40	19	1	2
Pioneer	18	36	6	2

Samples presented	SS	S?	N?	NS	R-index (%)
United Cane	a (1)	b (4)	c (33)	d (24)	56.80
United Beet	a (40)	b (19)	c (1)	d (2)	93.43
Pioneer	a (18)	b (36)	c (6)	d (2)	90.09
Noise	e (3)	f (3)	g (22)	h (34)	

$$\text{R-index} = \frac{[a(f+g+h) + b(g+h) + ch + \tfrac{1}{2}(ae + bf + cg + dh)]}{[(a+b+c+d)(e+f+g+h)]}$$

$$\text{R-index (\%)} = \frac{[18(3+22+34) + 36(22+34) + (6 \times 34) + \tfrac{1}{2}[(18 \times 3) + (36 \times 3) + (6 \times 22) + (2 \times 34)]}{[(18+36+6+2)+(3+3+22+34)]} \times 100\% = 90.09\%$$

Figure 4.7 Example of R-index calculations using data from aroma replication 1 test.

Table 4.10 R-index value (percentage) with combined replications.

	Sugar Source		
	United Sugar Corporation (Beet)	**Pioneer (Beet)**	**United Sugar Corporation (Cane)**
Sugar (Aroma)	93.00*	91.16*	57.78*
Sugar (Flavor)	75.80*	72.24*	68.10*
Pavlova	66.97*	71.94*	48.19
Simple Syrup	63.12*	69.84*	56.56
Sugar Cookie	38.86^{+}	45.16	40.17^{+}
Pudding	53.17	54.05	62.95*
Whipped Cream	38.26^{+}	41.67^{+}	38.62^{+}
Iced Tea	58.07*	52.65	52.99

$p<0.05$, n=124

* indicates that the R-index for that sample is above 57.108. This means that the panelists identified this sample as being significantly different from the noise sample

+ indicates that the R-index for that sample is below 42.892. This means that the panelists identified this sample as being confusable, yet significantly different from the noise sample.

Table 4.11 R-index value (percentage) separated by replication.

	Replication	Sugar Source		
		United Sugar Corporation (Beet)	Pioneer (Beet)	United Sugar Corporation (Cane)
Sugar (Aroma)	1	93.43*	90.09*	56.80
Sugar (Aroma)	2	92.61*	92.20*	58.74
Sugar (Flavor)	1	72.18*	69.16*	65.11*
Sugar (Flavor)	2	79.08*	75.39*	71.33*
Pavlova	1	77.17*	80.11*	44.33
Pavlova	2	56.89	64.61*	51.08
Simple Syrup	1	64.07*	75.03*	60.90*
Simple Syrup	2	62.49*	64.24*	52.30
Sugar Cookie	1	53.17	54.92	56.43
Sugar Cookie	2	22.52+	45.17	30.70+
Pudding	1	58.39	58.14	68.95*
Pudding	2	48.20	49.66	56.97
Whipped Cream	1	22.32+	36.97+	27.81+
Whipped Cream	2	56.48	43.24	50.29
Iced Tea	1	56.78	60.22*	63.64*
Iced Tea	2	60.47*	44.60	41.70

$p<0.05$, n=62

* indicates that the R-index for that sample is above 59.948. This means that the panelists identified this sample as being significantly different from the noise sample

+ indicates that the R-index for that sample is below 40.052. This means that the panelists identified this sample as being confusable, yet significantly different from the noise sample

Table 4.12 Least significant ranked difference (LSRD) multiple comparisons rank superscripts with combined replications.

	Ascending order of rank sums from most to least similar compared to the noise			
Sugar (Aroma)	CH(196)^{a}	UC(215)^{a}	P(390)^{b}	UB(439)^{c}
Sugar (Flavor)	CH(228)^{a}	UC(309)^{b}	P(340)^{bc}	UB(363)^{c}
Pavlova	UC(256)^{a}	CH(264)^{a}	UB(348)^{b}	P(372)^{b}
Simple Syrup	CH(261)^{a}	UC(287)^{a}	UB(330)^{b}	P(362)^{b}
Sugar Cookie	UB(290)^{a}	UC(293)^{a}	P(315)^{ab}	CH(342)^{b}
Pudding	CH(285)^{a}	UB(299)^{a}	P(304)^{a}	UC(352)^{b}
Whipped Cream	UB(291)^{a}	UC(292)^{a}	P(308)^{a}	CH(349)^{b}
Iced Tea	CH(293)^{a}	P(306)^{a}	UC(308)^{a}	UB(333)^{a}

CH= C&H (cane); P= Pioneer Sugar (beet); UC= United Sugar Corporation (cane); UB= United Sugar Corporation (beet)
The rank sums are presented in the parenthesis.
Means within a row that are noted with the same subscript letter indicate no significant differences ($p<0.05$) between sugar type for a given product.

Table 4.13 Least significant ranked difference (LSRD) multiple comparisons rank superscripts separated by replication.

	Replication	Ascending order of rank sums from most to least similar compared to the noise			
Sugar (Aroma)	1	CH(99)^{a}	UC(106)^{a}	P(194)^{b}	UB(221)^{b}
Sugar (Aroma)	2	CH(97)^{a}	UC(109)^{a}	P(196)^{b}	UB(218)^{b}
Sugar (Flavor)	1	CH(120)^{a}	UC(156)^{b}	P(169)^{b}	UB(175)^{b}
Sugar (Flavor)	2	CH(108)^{a}	UC(153)^{b}	P(171)^{bc}	UB(188)^{c}
Pavlova	1	UC(113)^{a}	CH(123)^{a}	UB(190)^{b}	P(194)^{b}
Pavlova	2	UC(141)^{a}	CH(143)^{a}	UB(158)^{ab}	P(178)^{b}
Simple Syrup	1	CH(124)^{a}	UC(146)^{ab}	UB(158)^{b}	P(192)^{c}
Simple Syrup	2	CH(137)^{a}	UC(141)^{a}	P(170)^{b}	UB(172)^{b}
Sugar Cookie	1	CH(146)^{a}	UB(154)^{a}	P(158)^{a}	UC(162)^{a}
Sugar Cookie	2	UB(120)^{a}	UC(138)^{a}	P(175)^{b}	CH(187)^{b}
Pudding	1	CH(133)^{a}	UB(152)^{a}	P(153)^{a}	UC(182)^{b}
Pudding	2	UB(147)^{a}	P(151)^{a}	CH(152)^{a}	UC(170)^{a}
Whipped Cream	1	UB(121)^{a}	UC(137)^{a}	P(168)^{b}	CH(194)^{b}
Whipped Cream	2	P(140)^{a}	CH(155)^{a}	UC(155)^{a}	UB(170)^{a}
Iced Tea	1	CH(136)^{a}	UB(151)^{a}	P(162)^{a}	UC(171)^{a}
Iced Tea	2	UC(137)^{a}	P(144)^{a}	CH(157)^{ab}	UB(182)^{b}

CH= C&H (cane); P= Pioneer Sugar (beet); UC= United Sugar Corporation (cane); UB= United Sugar Corporation (beet)
The rank sums are presented in the parenthesis
Means within a row that are noted with the same subscript letter indicate no significant differences (p<0.05) between sugar type for a given product.

Table 4.14 Percentage of sugar in the product formulation on a weight/weight basis.

	Percent sugar (w/w)
Sugar (Aroma)	100
Sugar (Flavor)	100
Pavlova	86.0
Simple Syrup	52.6
Sugar Cookie	28.4
Pudding	17.9
Whipped Cream	13.7
Iced Tea	8.0

$$\text{Percent sugar}\left(\frac{\text{w}}{\text{w}}\right) = \frac{\text{g sugar}}{\text{g sample}} * 100$$

Table 4.15 Magnitude of difference between replication one and replication two R-index values, indicating the variation between replications.

	United Sugar Corporation (Beet)	Pioneer (Beet)	United Sugar Corporation (Cane)
Sugar (Aroma)	0.82	2.11	1.94
Sugar (Flavor)	6.9	6.23	6.22
Pavlova	20.28	15.5	6.75
Simple Syrup	1.58	10.79	8.6
Sugar Cookie	30.65	9.75	25.73
Pudding	10.19	8.48	11.98
Whipped Cream	34.16	6.27	22.48
Iced Tea	3.69	15.62	21.94

Chapter 5: Does information about sugar source influence consumer liking of products made with beet and cane sugars?

5.1 Abstract

Refined sugar from sugar beet and sugar cane are both composed of greater than 99% sucrose. Though beet and cane sugars have nearly identical chemical compositions, the sugars differ in their analytically determined volatile profiles, thermal behaviors, minor chemical compositions, and their performance in some food products. The possibility of differences between beet and cane sugars has also gained the attention of consumers in popular press sources. The objective of the present study was to relate the impact of information labels that specified the sugar source in an orange flavored drink to overall liking of that drink. One hundred panelists evaluated orange flavored drink mix and beverage made with beet and cane sugars using a five-phase testing protocol involving a tetrad test and hedonic ratings performed in blind and informed information conditions. Tetrad test results indicated that there was a significant difference ($p<0.05$) between beet and cane sugars in the drink mix; however, panelists were not able to distinguish a difference in the beverage. Analysis of hedonic ratings revealed an information condition effect on panelists evaluation of sugar ($F=24.67$, $p<0.001$), though no effect was identified for the drink mix or beverage. Sample evaluations under informed conditions resulted in higher hedonic scores than those under blind conditions for all sample types, due to reduction in uncertainty. Results from this study are representative of the responses from the general population. Though the results from this study suggest that the provision of information regarding sugar source does not significantly influence product liking for the general population, the results may have been different if a specific subgroup of people with extensive knowledge or experience on or working with sugar was targeted to participate in the study. Based on concerns with the use of beet sugar expressed in the popular press, this subgroup may have a preconceived bias about sugar sources due to their prior experiences and knowledge.

5.2 Introduction

Beet and cane sugars, the primary sources of commercial sucrose, are nearly identical in terms of their chemical composition, containing greater than 99% sucrose (Potter and Mansel 1992; Colonna and others 2000; Asadi 2005). The remainder of their composition consists of water, trace components from the sugar plant source, and compounds inadvertently incorporated during processing (Colonna and others 2000). Though their chemical identities are comparable, studies have found differences in their analytically determined volatile profiles, thermal behaviors, minor chemical compositions, and their performance in some food products (Monte and Maga 1982; Marsili and others 1994; Pihlsgard 1997; Asadi 2005; Lu and others 2013; Urbanus 2014a Chapter 3; Urbanus 2014b Chapter 4).

The reputation of beet and cane sugars and their performance in products has also gained attention in the popular press, including Internet articles and blogs (Ridge 2001). Some users regard the two sugars as the same, while others argue that there is a noticeable difference between them. Harold McGee, a world-renowned authority on the chemistry of foods and cooking, provided insight on this subject, "…beet sugar sometimes carries traces of defensive chemicals called saponins… These are known to cause the development of a scum in syrups, and may also be responsible for the poor baking performance sometimes attributed to beet sugar. (This reputation may be an undeserved legacy of the early 20th century, when refining techniques weren't as effective and the quality of beet sugar often didn't measure up to that of cane sugar)" (McGee 2004). Additionally, Marion Cunningham, a cooking columnist and author, voiced her opinion in a newspaper article that beet and cane sugars yield different results in baking, depending on the recipe: "It *[the sugar source]* matters in recipes for baked goods like angel food cake. It just isn't right with beet sugar" (Morgan 1999). On the other hand, Ronald DeSantis, a Certified Master Chef from the Culinary Institute of America (CIA), contends otherwise. A letter from DeSantis (2007) to the United States Beet Sugar Association stated that a contractual independent study was conducted by the Culinary Institute of America in which six CIA recipes and six consumer mixes were made with both beet and cane sugars and evaluated using objective sensory testing. Specifics on the methodology, sample preparation, and data analysis, however, were not provided. The findings of the CIA project determined that "…sugar from sugar beets was shown to perform as functionally equivalent to cane sugar, with no discernible taste difference found in products evaluated in sensory testing" (DeSantis 2007). Many other popular press sources debate whether beet and cane sugars are perceptibly different, although currently, there is little supporting research evidence for either viewpoint.

Our previous research investigated possible sensory differences between beet and cane when incorporated in different product matrices (Urbanus 2014b Chapter 4). Panelists performed a difference test on beet and cane sugars in regard to their aroma and flavor, along with pavlova, simple syrup, sugar cookies, pudding, whipped cream, and iced tea made with beet and cane sugars. A difference ($p<0.05$) was found in the aroma and taste of beet and cane sugars and in the pavlova and simple syrup products made with beet and cane sugars; whereas no difference was observed in the other products tested. This study indicated that while there is a perceivable difference between beet and cane sugars, once the sugar has been incorporated into products a difference may not be detectable, depending on the product matrix. Based on the findings of Urbanus (2014b Chapter 4) which indicated the absence of a sensory difference in many products, it was hypothesized that perhaps the controversy regarding differences between beet and cane sugars when incorporated into some products is psychologically driven due to past experiences, product information, and marketing tactics.

In addition to sensory characteristics, psychological influences due to past experiences, product information, and marketing tactics are influential in ones perception of a food product. These factors often create expectations that can sway a consumer's perception of a product, even prior to consumption (Deliza 1996). Much research has been done to study the effect of information provided about a product on food related perceptions. For example, fat-free food products and their regular-fat counterparts (Tuorila and others 1994), smoked salmon ice cream (Yeomans and others 2008), beef (Van Wezemael and others 2012), and local apple juice (Stolzenbach and others 2013) have been studied to investigate this effect.

Research has shown that a malodor is often associated with beet sugar. Geosmin (*trans*-1,10-dimethyl-*trans*-(9)-decalol) and volatile fatty acids have been identified by analytical flavor chemistry techniques as the compounds responsible for this off-aroma (Marsili and others 1994; Godshall and others 1995; Moore and others 2004). These compounds give beet sugar a characteristic earthy and musty aroma. The present study will examine whether expectations due to the malodor in beet sugar influence consumers perception of products made using beet versus cane sugar.

The objective of the present study was to relate the impact of information labels that specified the sugar source in an orange flavored drink to overall liking of that drink. We hypothesized that consumer liking for the drinks would change depending on the information condition (blind or informed) in which they were evaluated and the sugar source that they contained. More specifically, we hypothesized that consumer liking of the drink containing beet sugar would decrease when evaluating the product in informed conditions compared to blind conditions, due to the off-aroma associated with beet sugar. To achieve the objective, a tetrad test was performed to determine whether a difference could be perceived in the products made with beet sugar versus those made with cane sugar and hedonic ratings were conducted in blind and informed conditions to determine the influence of information conditions on consumer liking of products made with beet and cane sugars.

5.3 Materials and Methods

Sample Selection

Orange flavored drink mix and orange flavored beverage were selected as the products used for evaluation. Orange flavored drink mix and beverage were chosen as the product matrix because the preparation protocol was simple, and, therefore, introduced little error due to processing variation. Previous findings indicated that sugar quantity in a product formula is a determinant in differentiating between beet and cane sugars in the product (Monte and Mage 1982; Urbanus 2014b Chapter 4). Therefore, these products were also chosen because the quantity of sugar in the drink mix formulation versus the beverage formulation were significantly different; the orange flavored drink mix contained 98% sugar and the beverage contained 12% sugar on a weight by weight basis.

The orange flavored drink mix and beverage were prepared using one brand of beet sugar, Pioneer Sugar, and one brand of cane sugar, C&H (Table 5.1). Initial instrumental screening and previous sensory evaluation results indicated that sugars of like sources from different manufacturers are nearly the same (Urbanus 2014a Chapter 3; Urbanus 2014b

Chapter 4). Therefore, one brand of beet sugar and one brand of cane sugar were selected as representative beet and cane sugar samples. Pioneer Sugar and C&H were chosen specifically because they are commercially available and generally recognized brands by consumers. All test ingredients were locally purchased (Urbana, IL).

Panelists

Panelists were comprised of one hundred consumers (77F and 23M, age range 18-55 yrs) recruited through a departmental e-mail listserv and flyers posted in campus buildings. Interested consumers completed a screening survey, which posed questions about their health status and availability (Figure 5.1). The answers to the survey were used for panel selection. Selected panelists were advised to not eat or drink at least 30 minutes prior to their scheduled session time. During the last testing session, panelists completed a questionnaire with demographic questions and sugar consumption and purchase behavior questions. At the completion of the study, panelists were compensated for their participation.

Sample Preparation

The orange flavored drink was evaluated by panelists in a dry mix and as a hydrated beverage. To prepare the orange flavored drink mix, unsweetened orange flavored Kool-Aid mix (1.8% w/w) (Kraft Foods Global Inc., Northfield, IL) and sugar (98.2% w/w), either beet or cane, were combined. The product formula was determined based on the directions provided on the Kool-Aid packet. To homogenize the Kool-Aid mix and sugar, ingredients were mixed in a KitchenAid Professional 600 series quart bowl-lift stand mixer (KitchenAid, St. Joseph, MI) with a metal whisk attachment. Approximately one gram (1/4 tsp) of the orange flavored drink mix was dispensed into each plastic 59.2 mL cup (Solo Cup Company, Inc., Chicago, IL). The cups were lidded and labeled with a randomized three-digit code, which corresponded to the source of the sugar used to make the mix.

To prepare the orange flavored beverage, unsweetened orange flavored Kool-Aid mix (0.2% w/w) (Kraft Foods Global Inc., Northfield, IL), purified water (87.8% w/w) (Absopure, Urbana, IL) and sugar (12% w/w), either beet or cane, and were combined. The product formula was determined based on the directions provided on the Kool-Aid packet. To homogenize the Kool-Aid mix and sugar, ingredients were mixed in a KitchenAid Professional 600 series quart bowl-lift stand mixer (KitchenAid, St. Joseph, MI) with a metal whisk attachment. The orange flavored drink mix was combined with water in a pitcher and mixed with a wooden spoon until homogeneous. Approximately 15 mL of the orange flavored beverage was distributed into each plastic 59.2 mL cup (Solo Cup Company, Inc., Chicago, IL). The cups were lidded and labeled with a randomized three-digit code, which corresponded to the source of the sugar used to make the beverage. Samples were refrigerated until 30 minutes prior to the start of the testing session.

Sugar samples were prepared by dispensing approximately one gram (1/4 tsp) of either beet or cane sugar into plastic 59.2 mL cups with lids (Solo Cup Company, Inc., Chicago, IL). The cups were labeled with a randomized three-digit code, which corresponded to the source of the sugar in the cup.

Test Design

The experiment took place in a room with partitioned booths maintained 22^{o}C and 33% relative humidity. Panelists evaluated the samples under incandescent lighting. At the beginning of an experimental session, participants rinsed their mouth with warm (26-29^{o}C) and room temperature purified water (Absopure, Urbana, IL). This rinse protocol was repeated between each subsequent sample. Following the rinse protocol, panelists evaluated samples side by side in order from left to right. Panelists were instructed to taste the entire contents of the cup at once and to expectorate all rinses and samples.

Consumer evaluation was divided into five phases including: 1) product difference test, 2) product liking evaluated in blind information conditions, 3) liking of sugar evaluated in blind information conditions, 4) liking of sugar evaluated in informed information conditions, and 5) product liking evaluated in informed information conditions (Figure 5.2). Each of the five phases was completed for the orange flavored drink mix and orange flavored beverage. Data from phase one were collected in sessions one and two; one day dedicated to the drink mix and the other to the beverage. Phase one was conducted on a separate day than the other phases to prevent panelist fatigue. Phases two through five for a single product (orange flavored drink mix or orange flavored beverage) was completed on a single test day. A new set of samples was presented for each phase with an enforced one-minute rest period between each set. The order of the steps remained constant among panelists, though the samples within each set were counterbalanced. Panelists participated in four sessions total, each lasting 15 to 20 minutes.

Phase 1: The tetrad test was comprised of two sessions, one for the orange flavored drink mix and one for the orange flavored beverage. During each of the sessions, panelists performed two tetrad tests; one tetrad test for aroma and the other for flavor. Flavor was defined as the sensory experience involving aroma and taste perceptions. During a session, panelists were served four samples side by side and instructed to evaluate the samples in order from left to right and sort the samples into two groups of two samples based on similarity. There was a one-minute break between each set of samples. All sample cups were labeled with randomized three-digit codes and the sample sets and samples within the set were randomized across the panelists. The randomization was a William's Latin Square design generated by the Compusense *five* Plus (Version 5.0: Guelph ON, Canada) data acquisition system.

Phase 2: Panelists evaluated two test samples, a product made with beet sugar and a product made with cane sugar. The sample cups were labeled with randomized three-digit codes and panelists were given no information about the samples to keep samples anonymous and avoid bias. Overall liking was rated on a 9-point hedonic scale anchored on 1=dislike extremely to 9=like extremely. This phase served as a baseline, measuring panelists' actual liking of the products without influence from information about the sugar source in the product.

Phase 3: Panelists evaluated two test samples, beet sugar and cane sugar. The sample cups were labeled with randomized three-digit codes and panelists were given no information about the samples to keep samples anonymous and avoid bias. Overall liking was rated on a 9-point hedonic scale anchored on 1=dislike extremely to 9=like extremely. The purpose of phase 2 was to collect hedonic scores for actual liking of sugar samples without influence from information about the source of the sugar.

Phase 4: Panelists evaluated two test samples, beet sugar and cane sugar. The sample cups were labeled indicating the source of the sugar, either beet or cane sugar, and with randomized three-digit codes. Overall liking was rated on a 9-point hedonic scale anchored on 1=dislike extremely to 9=like extremely. Evaluating the sugar under informed conditions increased panelists' familiarity with the sugars, hence generating associations between perceived sensory characteristics and sugar source. The data collected in phase 3 were to be compared to data from phase 2 to determine whether information conditions (blind and informed) influenced consumer liking of beet and cane sugars.

Phase 5: Panelists received two test samples, one sample made with beet sugar and the other made with cane sugar. Each cup was labeled as "made with beet sugar" or "made with cane sugar" in order to identify the source of sugar used to make the product. The sample cups were also labeled with a randomized three-digit code. Additionally, the panelists were given labeled cups of beet and cane sugar to use as a reference during evaluation. The reference samples were presented so that panelists could recall associations generated in phase 3. This was intentionally incorporated in the design to provoke expectations about test sample. Overall liking was rated on a 9-point hedonic scale anchored on 1=dislike extremely to 9=like extremely.

Data Analysis

The raw data were collected using Compusense *five* Plus (Version 5.0: Guelph ON, Canada). Data from phase 1 were analyzed using IFPrograms™ software (Version 8.1: Richmond, VA). Values of d' were calculated using IFPrograms™ software, but can also be calculated using tables (Ennis 1993; Bi and others 1997; Ennis and others 1998; Ennis and Jesionka 2011). d' is a measure of the size of the sensory difference between two products. The calculated binomial probabilities obtained from the program were compared to the significance level of 0.05.

Data from phases 2 through 5 were analyzed using Microsoft Excel and Statistical Analysis Systems Program (SAS version 9.3, SAS Institute Inc., Cary, NC). To determine whether sugar source and information conditions were influential in liking scores given to samples, hedonic scores were contrasted using ANOVA. Mean scores, F-values, and significance were computed. Sugar source, beet or cane sugar, and information condition, blind or informed, were used as factors. t-tests were also conducted to determine if samples from the same sugar source were influenced by information conditions.

5.4 Results and Discussion

The results from the tetrad test are summarized in Table 5.2. Data suggest that panelists could discriminate ($p<0.05$) between beet and cane sugars in the orange flavored drink mix when evaluating the samples by aroma and flavor. Panelists were not able to distinguish the difference between beet and cane sugars in the orange flavored beverage when evaluating the samples by aroma or by flavor.

Differences between beet and cane sugars were detectable in the orange flavored drink mix, but not in the orange flavored beverage due to the amount of sugar present. The products differed in the amount of sugar present on a weight by weight basis in the formulas. The orange flavored drink mix contained 98.2% sugar (w/w), while the orange flavored beverage contained 12% sugar (w/w). The amount of sugar in a product formula is one factor that affects the panelist's ability to differentiate between a product made with beet sugar versus a product made with cane sugar (Monte and Maga 1982; Urbanus 2014b Chapter 4).

Means and F-values were generated by ANOVA to evaluate sugar source (Table 5.3) and information conditions (Table 5.4). ANOVA of average hedonic scores indicated a significant difference between sugar source for the sugar samples ($F=82.75$, $p<0.001$) (Table 5.3). Cane sugar received a significantly greater liking score (5.838) compared to beet sugar (5.078). The results from the hedonic rating study corroborate previous research, which described beet sugar as having an undesirable aroma characterized as being off-dairy, oxidized, earthy, and barnyard like (Urbanus 2014a Chapter 3). It is likely that the lower liking score given to beet sugar is reflective of this characteristic off-aroma.

A significant information condition effect on panelists evaluation of sugar ($F=24.67$, $p<0.001$) was observed, though no significant effect was observed for the orange flavored drink mix or the beverage (Table 5.4). One possible explanation is that the information condition effect was significant with sugar but not with the orange flavored drink because there is a larger, and therefore more noticeable, sensory difference between beet and cane sugars compared to the difference between an orange flavored drink made with beet and cane sugars. The results indicate that information regarding sugar source did not significantly influence consumer liking of orange flavored drink mix or beverage.

The average liking scores and t-test comparison for the samples tested in the hedonic rating study are shown in Table 5.5. The beet sugar liking scores under blind conditions were significantly different than the liking scores under informed conditions. The same was true for the cane sugar. Although the effect of information conditions was only significant with sugar, all samples showed an increase in hedonic scores after the panelists were informed about the sugar source. The enhancement of product liking due to the availability of product information confirms trends observed in other studies (Allison and Uhl 1964; Tuorila and others 1994; Tuorila and others 1994; Stolzenbach and others 2013). Providing consumers with product information decreases the uncertainty about the identity of the food and hence increases product liking. When comparing scores across all sugar sources and information conditions within a product type, the sample containing cane sugar that was evaluated under informed conditions consistently received the higher liking score. This can be explained by expectations from exposure to the sugar. The objectionable odor characteristic of beet sugar may be responsible for expectations, which influenced subsequent product ratings (Marsili and others 1994; Godshall and others 1995; Moore and others 2004).

Though panelists could differentiate between the orange flavored drink mix made with beet sugar and the mix made with cane sugar in the tetrad test, the results from the hedonic rating study showed that the liking scores were not significantly different. As for the orange flavored beverage, panelists could not differentiate between the samples in the tetrad test and the hedonic liking scores were not influenced by the sugar source or information condition. The data for both products suggested that regardless of whether a difference could be detected between the products made with beet sugar and those made with cane sugar, liking scores were not influenced significantly by the sugar source or the information condition.

Panelists were exposed to beet and cane sugars prior to informed evaluation of the products in order to increase their familiarity with the sugar identities and to create an expectation. It was hypothesized that the off-aroma perceived in beet sugar would result in a negative perception, causing panelists to score products (orange flavored drink mix and orange flavored beverage) made with beet sugar lower under the informed condition compared to the blind condition. Interestingly, the results suggested the absence of this effect; information regarding sugar source had no impact on product liking. While evaluating the samples, information regarding the product being evaluated was deemed as being less important than the panelists' sensory experience.

The results from the present study are in contrast with what was hypothesized. It is possible that the liking scores from this study were not modified by information provided about the products due to the population of panelists who participated in this study. In the present study, the analysis yields results that are representative of the responses from the general population. However, the analysis does not consider how responses from different subgroups might differ. In general, the subgroup of the population participating in the blogs and Internet discussions concerning whether or not there is a differences between beet and cane sugars appear to favor one type of sugar source over the other (Morgan 1999). For this reason, liking scores of sugar containing products evaluated in blind versus informed conditions may have been significantly different if this subgroup were targeted for this study. Because this subgroup has a preconceived bias about sugar source, they would be expected to respond to information about the sugar source used in a product differently than the general population would respond. Existing research demonstrates the difference in response to product information by different subgroups (Allison and Uhl 1964; Shepherd and others 1991–1992; Aaron and others 1994).

Of the 100 panelists that participated in the study, 26 responded in the exit questionnaire that sugar source is an important deciding factor when purchasing sugar. The data from those 26 panelists were analyzed to determine the effect of product information regarding sugar source on the liking scores of this subgroup. Interestingly, scores for the orange flavored drink mix decreased when evaluated in informed compared to blind information conditions, regardless of the sugar source. The hedonic scores for beet sugar and the orange flavored beverage made with beet sugar remained nearly the same under the two different information conditions, although cane sugar and the orange flavored beverage made with cane sugar increased under the informed condition compared to the blind information condition. Overall, this subgroup that placed an importance on sugar source responded to the information about sugar source the same way as the panelist population on a whole. There was no difference between results from the subgroup and those from the entire panelist population because the power of the test was low due to the small sample size of the subgroup. To truly understand the impact of information conditions regarding sugar source on product liking for a subgroup who favors one type of sugar source over the other, a larger number of panelist is needed. Between 40 and 100 panelists is necessary for a consumer test to obtain an adequate power (Gacula and Rutenbeck 2006).

5.5 Conclusion

The pattern of hedonic ratings was not significantly changed when information about the sugar source was provided for the orange flavored drink mix and orange flavored beverage made with beet and cane sugars. Though the present study demonstrated no effect of providing information regarding sugar source on the liking ratings of orange flavored drinks for the general population, the results may have been altered if a specific subgroup was targeted for this study. People with prior knowledge and extensive experience with sugar, including seasoned bakers and food industry professionals, may favor one type of sugar source and hence have preconceived biases and expectations about sugar from different sources. It is hypothesized that these preconceived biases and expectations would influence this subgroups liking scores of sugar containing products, which would be reflected in significant differences in their liking scores in blind and informed conditions. This is an important avenue to explore in future research.

Results from the present study have important implications for the food industry. Currently, food companies are not required to specify the sugar source on a food label. The findings from this study indicate that specifying the sugar source on a food product label, in particular an orange flavored drink, does not influence the general populations overall liking of the product. Therefore, in general, it is not necessary for food companies to provide this information on food labels, though it is a factor that should be considered based on their target population.

5.6 References

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Table 5.1 Source, brand, manufacturer, distribution location, bag size, and lot number of sugar samples.

Source	Brand	Manufacturer	Location	Bag Size	Lot Number
Beet	Pioneer Sugar	Michigan Sugar Company	Bay City, MI	5lb	Y082C
Cane	C&H	ASR Group	Crockett, CA	4lb	52426 A2

Thank you for your interest in participating in this consumer testing study. To identify if you qualify for the study please provide answers to the following questions. If you have met qualifications for the study, you will be contacted with a testing schedule based on your listed availability. Your answers to these questions will be confidential and will be seen only by the researchers

Name: _____
Email Address: _____
Cell Phone Number: _____

1. **Do any of the following apply to you?**

   Follow a restricted diet for medical or personal reasons ☐ YES ☐ NO

   Diabetic ☐ YES ☐ NO

   Food or beverage allergies/sensitivities ☐ YES ☐ NO
   If so, please list the foods that you are allergic or sensitive to:

2. **Are you at least 18 years old?** ☐ YES ☐ NO

3. **You MUST be able to attend at least one 30 minute session on October 23, 28, 30 and November 4 and 6 OR October 24, 29, 31 and November 5 and 7. Check times ALL times that you are available for testing.**

	Monday	Tuesday	Wednesday	Thursday
9:00-9:30am	☐	☐	☐	☐
10:00-10:30am	☐	☐	☐	☐
11:00-11:30am	☐	☐	☐	☐
12:00-12:30pm	☐	☐	☐	☐
1:00-1:30pm	☐	☐	☐	☐
2:00-2:30pm	☐	☐	☐	☐
3:00-3:30pm	☐	☐	☐	☐
4:00-4:30pm	☐	☐	☐	☐
8:30-9:00am	☐	☐	☐	☐
9:30-10:00am	☐	☐	☐	☐
10:30-11:00am	☐	☐	☐	☐
11:30-12:00pm	☐	☐	☐	☐
12:30-1:00pm	☐	☐	☐	☐
1:30-2:00pm	☐	☐	☐	☐
2:30-3:00pm	☐	☐	☐	☐
3:30-4:00pm	☐	☐	☐	☐
4:30-5:00pm	☐	☐	☐	☐

Thank you for taking our survey! Your response is very important to us.

Figure 5.1 Screening survey used for panelist recruitment.

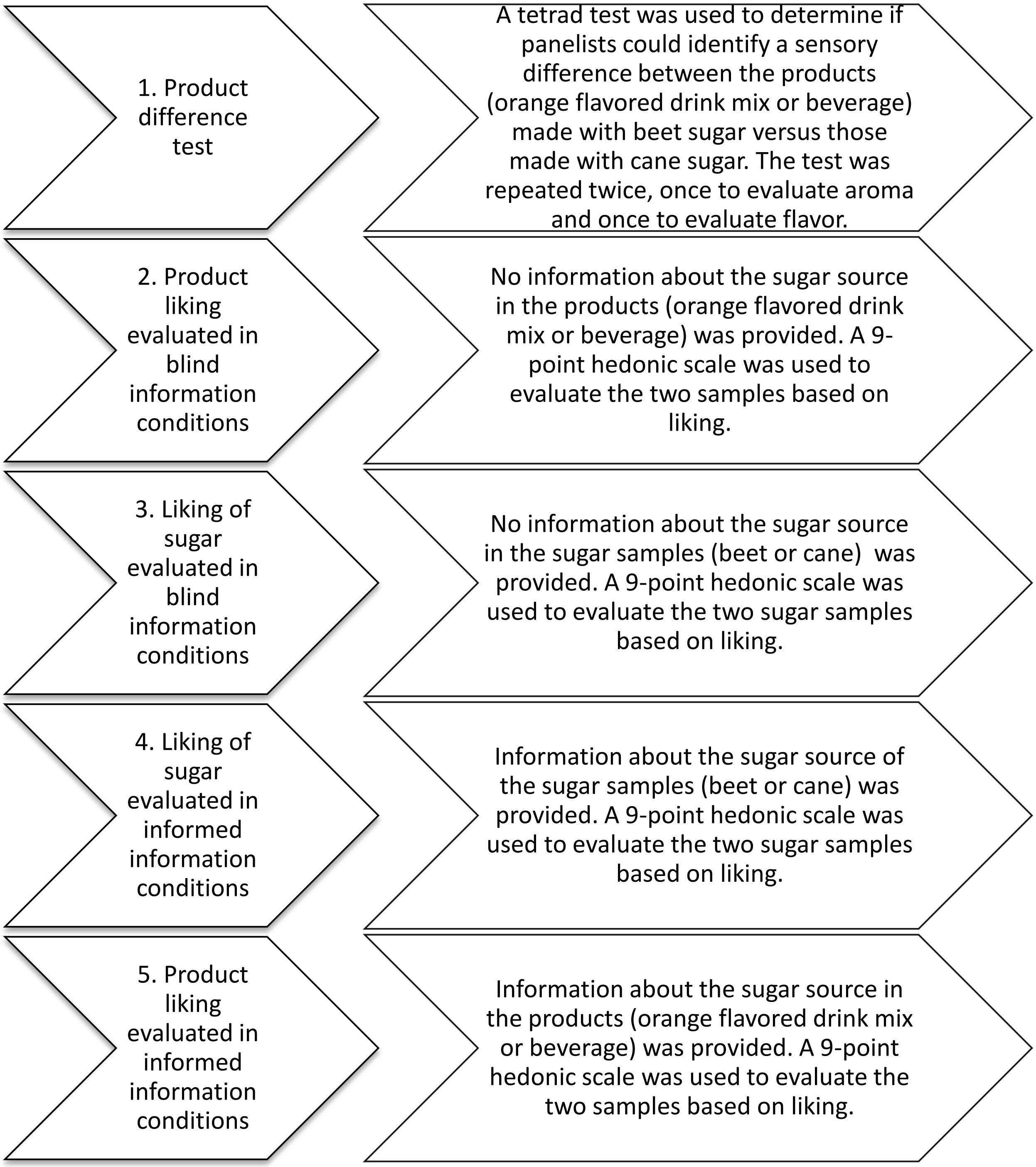


Figure 5.2 Schematic of experimental procedure illustrating the steps involved in the consumer evaluation.

Table 5.2 Tetrad test results by modality and product type: percent of correct responses, d', and binomial probabilities for sample differences.

Modality	Product Type	% Correct[a]	d'	p-value
Aroma	Kool-Aid Mix	66	1.56	0.00*
	Kool-Aid Beverage	37	0.45	0.25
Flavor	Kool-Aid Mix	50	1.02	0.00*
	Kool-Aid Beverage	40	0.62	0.10

* indicates significance at p<0.05
[a] percent correct based on the total sample size of 100 panelists.

Table 5.3 Mean hedonic scores and F-values computed by analysis of variance on sugar, orange flavored drink mix, and orange flavored beverage to evaluate sugar source (beet and cane).

	Sugar Source		F-value
Product Type	Beet	Cane	
Sugar	5.078	5.838	82.75***
Orange Flavored Drink Mix	6.155	6.305	1.14
Orange Flavored Beverage	6.250	6.345	0.78

Samples were evaluated on a 9-point scale
F-values are shown for source variation with *,**,*** indicating significance at p<0.05, p<0.01, and p<0.001, respectively

Table 5.4 Mean hedonic scores and F-values computed by analysis of variance on sugar, orange flavored drink mix, and orange flavored beverage to evaluate information condition (blind and informed).

	Information Condition		F-value
Product Type	Blind	Informed	
Sugar	5.250	5.665	24.67***
Orange Flavored Drink Mix	6.135	6.325	1.82
Orange Flavored Beverage	6.225	6.370	1.83

Samples were evaluated on a 9-point scale
F-values are shown for source variation with *,**,*** indicating significance at p<0.05, p<0.01, and p<0.001, respectively

Table 5.5 Mean hedonic scores for the sugar, orange flavored drink mix, and orange flavored beverage containing beet or cane sugar, under blind and informed information conditions.

Product Type	Sugar Source	Information Condition*	
		Blind	Informed
Sugar	Beet	4.95[a]	5.21[b]
	Cane	5.55[a]	6.13[b]
Orange Flavored Drink Mix	Beet	6.06[a]	6.25[a]
	Cane	6.21[a]	6.40[a]
Orange Flavored Beverage	Beet	6.24[a]	6.26[a]
	Cane	6.21[a]	6.48[a]

*Means within a row that are noted with the same subscript letter indicate no significant differences (p<0.05) between information condition for a given product determined by paired t-test

Chapter 6: Conclusion

Sugar is an important worldwide commodity that serves various purposes in food applications. Beet and cane sugars, the primary sources of sugar, are both composed of greater than 99% sucrose. Despite the nearly identical chemical composition, differences in their analytically determined volatile profiles, thermal behaviors, and minor chemical compositions have been reported. However, little published scientific research was found that explores the sensory properties of beet and cane sugars. Thus, this research was designed to differentiate beet and cane sugars, alone and in different product matrices, in terms of their sensory profiles.

Findings from this research indicate that the sensory characteristics are, in fact, another differential marker between beet and cane sugars. Panelist evaluations from the tetrad difference test suggest that beet and cane sugars can be differentiated by their aroma-only and taste and aroma without nose clips. To elaborate on these findings, a descriptive analysis test was employed, which characterized the differences and degree of differences between beet and cane sugars. Beet sugar was characterized by off-flavors including off-dairy, oxidized, earthy, and barnyard aromas and by a burnt sugar aroma-by-mouth and aftertaste. On the other hand cane sugar was described by sweet and fruity attributes. These findings corroborate previous studies, which utilized analytical flavor chemistry techniques to isolate off-aromas in beet sugar.

Based on the knowledge obtained from these studies, differences between beet and cane sugars reside in their aromas. The findings suggest that beet sugar manufacturers should implement a deodorization strategy to overcome the off-aroma perceived by consumers in beet sugar. Strategies such as the use of odor scavenging packaging or additional sugar crystal washing steps should be studied in the future to provide recommendations to beet sugar manufacturers for product quality improvements.

Differentiation between beet and cane sugars in various product matrices was determined using R-index by ranking. Of the eight products assessed by the panelists, a significant difference between beet and cane sugars was only perceived in the aroma of sugar, flavor of sugar, pavlova, and simple syrup. Panelists could not discern between beet and cane sugars in the sugar cookie, pudding, whipped cream or iced tea. The flavor and/or complexity of the product, the quantity of sugar in the formulation, and the processing protocol for the product are influential factors in distinguishing beet and cane sugars in a product. These findings provide insight to food manufacturers by suggesting additional factors to consider when formulating a product with sugar.

Due to the findings from the R-index study, future research should further explore the nature of the difference that was identified in the simple syrup and pavlova made with beet and cane sugars. Panelists could characterize the difference found in these products using descriptive analysis. Additional research is also needed to investigate the cause of the observed texture difference in the pavlova made with beet compared to cane sugar. Another avenue to explore based on the findings from this study is the influence of sugar quantity and matrix/flavor complexity on the perception of a difference between beet and cane sugars. These factors were hypothesized to be important based on findings from the research in this thesis, but additional research is needed to verify the significance of these factors. A difference test comparing sugar solutions made with beet and cane sugar at different concentrations could provide more insight about the influence of sugar quantity. Additionally, other difference tests can be performed to evaluate different products in order to acquire more insight on product matrices where beet and cane sugars are not interchangeable.

The relationship between information labels that specified the sugar source in an orange flavored drink and the overall liking of that drink was determined as well. Panelists evaluated an orange flavored drink mix and beverage in a five-phase consumer test involving a tetrad test and hedonic ratings performed in blind and informed information conditions. Though data indicated that information conditions do not significantly influence the liking scores of the drink mix or beverage for the general population, results may have differed if a specific subgroup was targeted for the study. A subgroup consisting of people with extensive knowledge or experience on or working with sugar, including seasoned bakers and food industry professionals, likely favor one type of sugar source and therefore, have a preconceived bias about beet and cane sugars. In this situation, the liking scores from this subgroup would be expected to change depending on the information conditions. A future research study should involve determining the impact of information conditions on the perceived liking of products containing beet and cane sugars evaluated by the subgroup of the population that favors one type of sugar source over the other. Comparing results from this specific subgroup to the results generated by the general population in chapter 5 of this thesis would provide important insight to food developers and marketers.

Overall, the research in this thesis is of importance because it documents the differences between beet and cane sugar sources from a sensory perspective. Knowledge on sensory differences supports the analytically determined volatile profile differences reported in the literature. Findings from this study impact sugar manufacturers, in particular beet sugar manufacturers, by illustrating the importance of aroma in sugar. Beet sugar manufacturers can use this knowledge to implement strategies that overcome the off-aroma perceived in beet sugar.

Implications of this research can also likely benefit the development of food products containing sugar. The learnings serve to guide the formulation and marketing of these products by offering recommendations based on scientific findings. Besides the market price, developers must also consider the flavor and/or complexity of the product, the quantity of sugar in the formulation, and the processing protocol for the product when deciding which sugar source to use. The interaction between sensory responses and product labeling information also needs to be considered in the marketing and development of sugar containing products based on the target market.

Appendix A: Letter written from the Culinary Institute of America to United States Beet Sugar Association.

The Culinary Institute of America
1946 Campus Drive
Hyde Park, NY 12538-1499
Tel: 845-452-9600
www.ciachef.edu

THE WORLD'S PREMIER CULINARY COLLEGE

November 16, 2007

Mr. James W. Johnson, President
United States Beet Sugar Association
1156 Fifteenth Street, NW; Suite 1019
Washington, DC 20005

Dear Mr. Johnson:

On August 22, 2007, the Culinary Institute of America entered into an agreement with the United States Beet Sugar Association to conduct a detailed sensory analysis of beet sugar vs. cane sugar in various recipes and food preparations. An analysis was undertaken at the CIA's Hyde Park, New York campus, with sensory evaluations and testing reviews performed by Certified Master Chefs and Certified Master Bakers on September 21, 2007, and on October 4, 2007.

In the course of the project, tests were executed under the most demanding of conditions using a variety of select cooking and baking techniques in preparation of 12 food items, including CIA Gold Standard core recipes and consumer-available retail products. Each food item was prepared twice, with beet sugar in one version and cane sugar in the other. No recipe changes other than the substitution of beet sugar for cane sugar were allowed. Items evaluated by CIA culinary, baking and pastry faculty included:

CIA Gold Standard Recipes (09/21/07)
- Corn Muffins
- Fudge Brownies
- Cheesecake
- Vanilla Sauce
- Créme Brulee
- Tuille Cookies

Consumer Product Tasting Items (10/04/07)
- Bisquick® Pancakes
- Pioneer® Buttermilk Biscuit Fruit Cobbler
- Jiffy® All-Purpose Baking Mix Sugar Cookies
- Kool-Aid®
- Steel-cut Oatmeal
- Cream of Wheat® hot cereal

With respect to the beet sugar vs. cane sugar sensory evaluation conducted through objective testing by the CIA, the following statement summarizes the findings of the project:

> *In an independent study conducted by The Culinary Institute of America's Industry Solutions Group, sugar from sugar beets was shown to perform as functionally equivalent to cane sugar, with no discernable taste difference found in products evaluated in sensory testing.*

Sincerely,

Ron DeSantis

Ronald DeSantis, MBA
Certified Master Chef
Director, Industry Solutions Group

Appendix B: Results from the preliminary sensory study by Monte and Maga (1982).

TABLE 1

INFLUENCE OF TEMPERATURE, SUCROSE SOURCE, AND CONCENTRATION ON A 40-MEMBER SENSORY TRIANGLE TEST

Temp. (°C)	Concentration (Wt. % in H_2O)	No. Correct Responses Cane vs. Beet	Significant (α = 0.05)
4	0.1	14	No
	0.5	12	No
	1.0	15	No
	2.0	17	No
	4.0	16	No
	8.0	17	No
	16.0	19	Yes
22	0.1	13	No
	0.5	16	No
	1.0	17	No
	2.0	22	Yes
	4.0	25	Yes
	8.0	31	Yes
	16.0	34	Yes
35	0.1	16	No
	0.5	24	Yes
	1.0	27	Yes
	2.0	31	Yes
	4.0	35	Yes
	8.0	35	Yes
	16.0	38	Yes

Appendix C: Local retail price of beet and cane sugars.

Brand	Store	Weight	Price	$/lb	Beet/Cane*
County Market Sugar	County Market (Champaign, IL)	10lb	$5.99	0.5990	Beet?
Crystal Sugar	County Market (Champaign, IL)	4lb	$2.99	0.7475	Beet?
Granulated sugar- Michigan sugar company	Walmart (Savoy, IL)	4lb	$2.04	0.5100	Beet?
Great Value	Walmart (Savoy, IL)	5lb	$2.88	0.5760	Beet?
Market Pantry	Target (Champaign, IL)	10lb	$6.54	0.6540	Beet?
	Target (Champaign, IL)	4lb	$2.39	0.5975	Beet?
Schnucks	Schnucks (Urbana, IL)	4lb	$2.59	0.6475	Beet?
C&H	Schnucks (Urbana, IL)	4lb	$2.99	0.7475	Cane
	Walmart (Savoy, IL)	4lb	$2.64	0.6600	Cane
	County Market (Champaign, IL)	4lb	$2.69	0.6725	Cane
Domino	Target (Champaign, IL)	10lb	$6.99	0.6990	Cane
	Target (Champaign, IL)	4lb	$2.64	0.6600	Cane
TW	County Market (Champaign, IL)	4lb	$2.39	0.5975	Cane

Average price per pound

Beet sugar?: $0.62 Cane sugar: $0.67

*Bags of sugar that were not labeled with the sugar source were assumed to be beet sugar and were therefore designated as "Beet?" in the table.

Appendix D: Consent form for descriptive analysis panel.

You are invited to participate in a study involving sensory evaluation of sugars. The goal of this research is to establish the descriptive profiles of several commercial grade sugars. The sugars will be evaluated using a descriptive analysis method. You will be asked to taste each sample and rate it in terms of a series of descriptive attributes. Since the reference products used to rate the samples are to be decided by the panel of participants, potential allergens involved in the study are yet to be determined. Therefore, if you have any food allergies, you should not participate in this study. You are free to withdraw from the study at any time for any reason.

The study will be conducted in Bevier Hall Room 376 and 372. There will be four sessions lasting approximately 60 minutes. Additionally, on booth testing session day you will be asked to attend two 30 minute sessions equaling 60 minutes. The total number of sessions required for each panelist is 6 and the total time commitment is 5 hours. Participation in the study will be voluntary. You are free to withdraw at any time during the course of the study. The experimenter(s) also reserve the right to terminate the participation of an individual subject at any time. You will be terminated if you miss sessions, are consistently late, or cannot follow directions.

Your performance in this study is confidential. Prescreening responses will be coded and separated from identifying information to maintain confidentiality. Sample evaluation responses are coded to be anonymous and any publications or presentations of the results of the research will only include information about group performance.

You are encouraged to ask any questions about this study whether before, during, or after your participation. However, specific questions about the samples that could influence the outcome of the study will be deferred to the end of the experiment. Questions can be addressed to Dr. Soo-Yeun Lee (217-244-9435, soolee@illinois.edu) or Brittany Urbanus (847-772-2346, urbanus1@illinois.edu). You may also contact the IRB Office (217-333-2670, irb@illinois.edu) for any questions about the rights of research subjects. If you live outside the local calling area, you may also call collect.

I understand the above information and voluntarily consent to participate in the study described above.

- ☐ I have been offered a copy of this consent form.
- ☐ I am 18 years of age or older.

Signature________________________________ Date____________________

Print Name____

Appendix E: Preliminary questionnaire screening form for R-index by ranking study.

Thank you for your interest in participating in this consumer testing study. Prior to your participating in this test, I'd like to ask you some questions. Your answers to these questions will be confidential and will be seen only by the researchers. If you have any questions or concerns, feel free to contact Brittany Urbanus at Illinois.sensory.urbanus@gmail.com.

Name: _____ **Email Address:** _____

1. **Are you available to participate every Tuesday and Thursday from February 5, 2013 to February 28, 2013?** ☐ YES ☐ NO
2. **Are you over 18 years old?** ☐ YES ☐ NO
3. **Are you allergic to any foods?** ☐ YES ☐ NO
   If yes, please list the foods you're allergic to:
4. **Desired time to participate: Check times when you are available to participate. You MUST be able to attend at least one 30 minute session on each of the days listed below**

Time of Day	Availability							
	T., Feb. 5	Th., Feb. 7	T., Feb. 12	Th., Feb. 14	T., Feb. 19	Th., Feb. 21	T., Feb. 26	Th., Feb. 28
9:00-9:30am	☐	☐	☐	☐	☐	☐	☐	☐
10:00-10:30am	☐	☐	☐	☐	☐	☐	☐	☐
11:00-11:30pm	☐	☐	☐	☐	☐	☐	☐	☐
12:00-12:30pm	☐	☐	☐	☐	☐	☐	☐	☐
1:00-1:30pm	☐	☐	☐	☐	☐	☐	☐	☐
2:00-2:30pm	☐	☐	☐	☐	☐	☐	☐	☐
3:00-3:30pm	☐	☐	☐	☐	☐	☐	☐	☐
4:00-4:30pm	☐	☐	☐	☐	☐	☐	☐	☐

Appendix F: Consent form for R-index by ranking study.

You are invited to participate in a study involving sensory evaluation of naturally sweetened ingredients and products. The goal of this research is to determine whether a difference can be detected between the samples. The products will be evaluated using a ranking method. You will be asked to taste or smell two sets of four samples and compare the samples in each set to the "Noise" sample presented with that set. You are to put the four samples in order by how similar they are to the "Noise", 1 being most similar and 4 being least similar. There are no risks to you beyond those of everyday life. Known allergens involved with the products in this study are gluten and dairy products. A complete list of ingredients is available for review. If you are allergic to any of these products or have diet restrictions due to medical concerns such as diabetes, you should not participate in this study. The University of Illinois does not provide medical or hospitalization insurance coverage for participants in this research study nor will the University of Illinois provide compensation for any injury sustained as a result of participation in this research study, except as required by law. You are free to withdraw from the study at any time for any reason and it will have no effect on your grades at, status at, or future relations with the University of Illinois.

Your participation in this study is confidential. Prescreening responses will be coded and separated from identifying information to maintain confidentiality. Sample evaluation responses are coded to be anonymous and any publications or presentations of the results of the research will only include information about group performance. Images taken during the panel may be used in oral or poster presentations of the research. Names of panelists will not be attached to the images. Data gathered from the entire project will be summarized in the aggregate, excluding references to any individual responses. The aggregated results of our analysis will be for journal articles and conference presentations. Again, your input is very important to us and any information we receive from you will be kept secure and confidential.

You will be participating in 8, 30 minute session. Participation in the study will be voluntary. You are free to withdraw at any time during the course of the study. The experimenter(s) also reserve the right to terminate the participation of an individual subject at any time. You will be terminated if you miss sessions, are consistently late, or cannot follow directions. Upon completion of the study, you will be compensated with $40. If you do not complete the study, you will be compensated for your time at a rate of $8/hour.

You are encouraged to ask any questions about this study before, during, or after your participation. However, specific questions about the samples that could influence the outcome of the study will be deferred to the end of the experiment. Questions can be addressed to Dr. Soo-Yeun Lee (217-244-9435, soolee@illinois.edu) or Brittany Urbanus (847-772-2346, urbanus1@illinois.edu). You may also contact the IRB Office (217-333-2670, irb@illinois.edu) for any questions about the rights of research subjects. If you live outside the local calling area, you may also call collect.

I understand the above information and voluntarily consent to participate in the study described above.

- ☐ I have been offered a copy of this consent form.
- ☐ I am 18 years of age or older.
- ☐ I agree to have photographs taken of me while participating in this research.

Signature Date

Print Name

Appendix G: Baker observations of the pavlova during production for the R-index by ranking study.

		United Sugar Corporation (Beet)		Pioneer (Beet)		United Sugar Corporation (Cane)		C&H		
		Rep 1	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Noise**
Batter	**Stiff peak?**	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Shiny?	Yes, very	Yes	Somewhat. Not as much as others	Yes, very shiny	Yes, but not too shiny	Yes, shinier compared to other batches	Somewhat shiny	Slightly shiny	Somewhat shiny
	Stiffness	Very stiff				Holds shape	Holds shape	Holds shape	Stiff, holds shape well	
	Airiness	Airy with some holes	Pretty dense but fluffy	Fairly dense	Dense, heavy	Fluffy	Dense	Dense	Dense	Heavy, dense, but light
	Color	Bright white	Bright white	Bright white	Bright white	Pure white	Pure white	Pure white		Bright white
After baking	**Color**	Mostly white, some golden	Mostly white, a little brown	Mostly white, some light brown	Cream/ off white with brown	Slightly cream and some are slightly golden brown	White, some cream, some golden. Some shiny	Cream and golden brown	White, cream with some brown	Off white, cream with some light brown
	Texture	Stiff, Styrofoam	Slightly puffy. Stiff	Stiff	Styrofoam	Styrofoam	Hard, Styrofoam	Hard, Styrofoam	Styrofoam	Light, puffy
	Stickiness	A little sticky on bottoms	A little sticky on bottoms	A little sticky on bottoms	Not sticky	Not very sticky	Not very sticky	Not very sticky	Not sticky	Not very sticky

Appendix H: Baker observations of the simple syrup during production for the R-index by ranking study.

	United Sugar Corporation (Beet)		Pioneer (Beet)		United Sugar Corporation (Cane)		C&H		
	Rep 1	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Noise**
Sugar dissolve easily?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Color/ transparency	Very cloudy	Cloudy	Very cloudy	Cloudy	Very cloudy	Cloudy	Very cloudy	Cloudy	Cloudy
Aroma	Sweet, burnt	A little sweet	Sweet	A little sweet	Sweet, a little burnt	A little sweet	Sweet	Sweet	A little sweet
Thickness after cooling	Soupy		Thin, soupy	Thin, soupy	Runny, soupy	Thin, soupy	Thin, soupy	Thin	Thin
Temperature before removing from heat (F)	215	211	212	214	207	217	217	215	216

Appendix I: Baker observations of the sugar cookies during production for the R-index by ranking study.

		United Sugar Corporation (Beet)		Pioneer (Beet)		United Sugar Corporation (Cane)		C&H		
		Rep 1	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Noise**
Dough	**Color**	Pale yellow/ cream	Pale yellow/ cream	Pale yellow/ cream	Light yellow/ cream	Pale yellow/ cream	Pale yellow/cream	Pale yellow/ cream/ off white	Light yellow/ cream	Pale yellow/ cream
	Stickiness	Not sticky. Sticks together well	Not sticky. Sticks together well	Slightly sticky	Not very sticky. Sticks together when compressed	Not sticky. Sticks together well	Not sticky. Sticks together well	Not very sticky. Sticks together well	Not sticky. Sticks together well	
	Texture	Slightly crumbly.	Slightly crumbly.	Slightly crumbly. Smooth.	Slightly crumbly. Smooth.	Creamy. Slightly crumbly	Creamy. Slightly crumbly	Slightly more crumbly.	Soft, creamy, smooth	Soft, creamy, very dense, slightly crumbly
Cookie	**Color**	Light tan to semi golden brown	Slightly tan to semi golden brown	Light tan to golden brown.	Light brown.	Slightly tan	Slightly tan to semi golden brown	Some are slightly golden brown	Tan- light golden brown	Light tan to golden brown.
	Texture	Semi-flaky/ crumbly. Cracked in a few places.	Semi-flaky/ crumbly. Cracked in a few places.	A little cracked.	Hard exterior. Cracked/ crumbly	Somewhat flaky and cracked surface	Very hard exterior. Cracked. Crummy	Very flaky. Lots of surface cracks.	Hard exterior. Cracked surface	Hard exterior. Flaky, cracked/ crumbled
	Spread and height	Rose slightly	Rose slightly		Slight rise and spread	Not much spread. Elevated in height slightly		Rose a little bit.	Dome like structure	

Appendix J: Baker observations of the pudding during production for the R-index by ranking study.

		United Sugar Corporation (Beet)		Pioneer (Beet)		United Sugar Corporation (Cane)		C&H		
		Rep 1	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Noise**
While cooking	**Color**	Cream/ pale yellow	Pale yellow	Pale yellow/ cream	Pale yellow	Light yellow	Pale yellow	Pale yellow	Pale yellow	Pale yellow
	Thickness	Liquidy	Liquidy	Liquidy	Liquidy	Liquidy	Thin	Liquidy	Thin	Liquidy
	Aroma	None	None	None	None		None	None	None	None
After cooking	**Color**	Golden yellow	Light golden yellow	Light golden yellow	Light golden yellow	Golden yellow	Golden yellow	Golden yellow	Golden yellow	Light/ pale golden yellow
	Texture	Smooth, creamy	Smooth, creamy	Smooth, creamy	Smooth, creamy	Creamy	Creamy, smooth, not lumpy	Creamy, not very lumpy	Creamy, smooth, not lumpy	Smooth, creamy

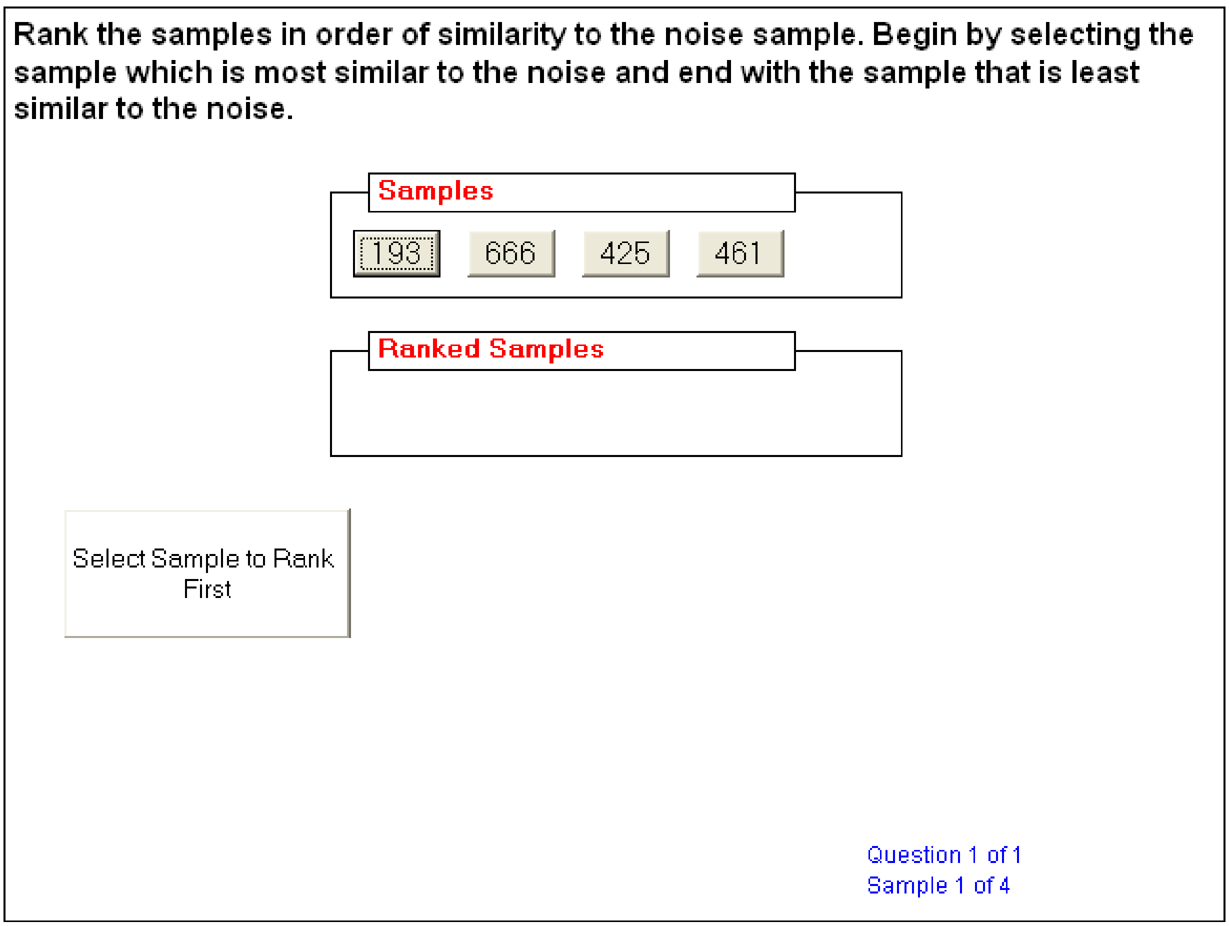
Appendix K: Baker observations of the whipped cream during production for the R-index by ranking study.

	United Sugar Corporation (Beet)		Pioneer (Beet)		United Sugar Corporation (Cane)		C&H		
	Rep 1	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Noise**
Stiff peak?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Appearance	Shiny with some lumps	Shiny with some lumps	Shiny, lumps, smooth texture	Shiny, slightly lumpy	Shiny, few lumps, smooth texture	Shiny. Some air pockets, some lumps	Shiny, glossy, some lumps	Shiny with some air pockets	Shiny, glossy, smooth

Appendix L: Baker observations of the iced tea during production for the R-index by ranking study.

	United Sugar Corporation (Beet)		Pioneer (Beet)		United Sugar Corporation (Cane)		C&H		
	Rep 1	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Rep 1**	**Rep 2**	**Noise**
Dissolve	Iced tea took longer to dissolve	Dissolved quickly	Dissolved well	Dissolved quickly	Dissolved well once mixed	Dissolved quickly	Took longer to dissolve and iced tea never fully dissolved	Iced tea took longer than sugar, but both dissolved	Took a while longer but dissolved fully
Foam?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
How much foam? (0-10)	9	7	6	5	9	6	7	6	8

Appendix M: Screenshot from Compusense *five* Plus of the scorecard for the R-index by ranking study.



Appendix N: Pictures of the pavlova from the R-index test.

NOISE= C&H, UC= United Sugar (Cane), UB= United Sugar (Beet), P=Pioneer
B1= Batch 1, B2= Batch 2

NOISE UC-B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2

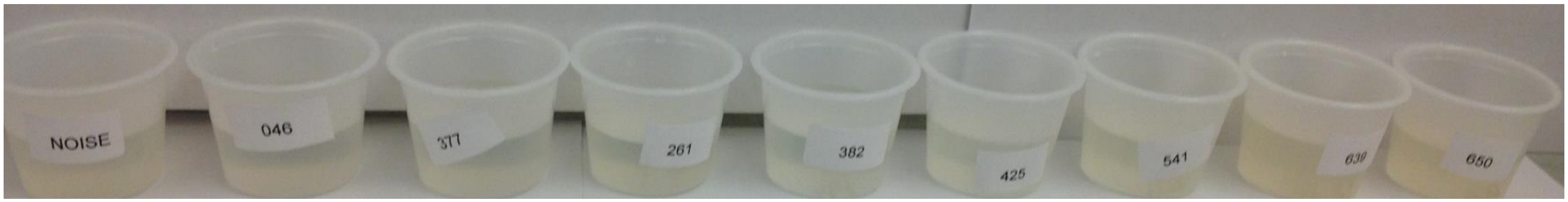
NOISE UC-B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2

NOISE UC-B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2

Appendix O: Pictures of the simple syrup from the R-index test.

NOISE= C&H**,** UC= United Sugar (Cane), UB= United Sugar (Beet), P=Pioneer

B1= Batch 1, B2= Batch 2

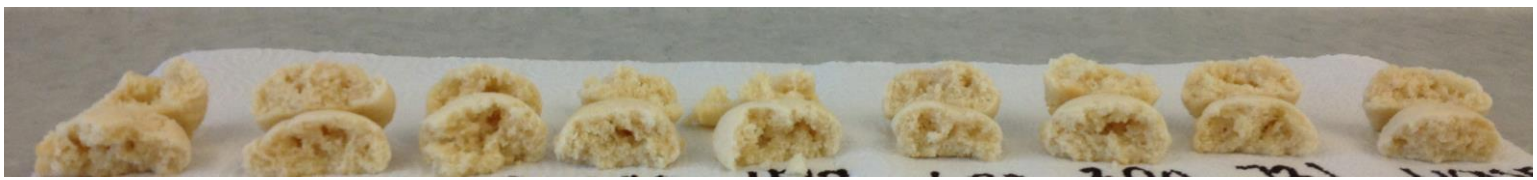


NOISE UC- B1 UC- B2 C&H- B2 UB- B1 UB- B2 C&H- B1 P- B2 P- B1

NOISE UC- B1 UC- B2 C&H- B2 UB- B1 UB- B2 C&H- B1 P- B2 P- B1

Appendix P: Pictures of the sugar cookies from the R-index test.
NOISE= C&H**,** UC= United Sugar (Cane), UB= United Sugar (Beet), P=Pioneer
B1= Batch 1, B2= Batch 2

UC- B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2 NOISE



UC- B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2 NOISE

UC- B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2 NOISE

Appendix Q: Pictures of the pudding taken two days after testing for the R-index test.

NOISE= C&H, UC= United Sugar (Cane), UB= United Sugar (Beet), P=Pioneer
B1= Batch 1, B2= Batch 2

NOISE UC- B2 UB- B1 UC- B1 C&H-B1 P- B2 UB- B2 C&H- B2 P- B1

NOISE UC- B2 UB- B1 UC- B1 C&H-B1 P- B2 UB- B2 C&H- B2 P- B1

Appendix R: Pictures of the whipped cream taken the day of testing for the R-index test.

NOISE= C&H, UC= United Sugar (Cane), UB= United Sugar (Beet), P=Pioneer

B1= Batch 1, B2= Batch 2

NOISE C&H- B1 UB- B1 UC- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2

NOISE C&H- B1 UB- B1 UC- B1 P- B1 UC- B2 UB- B2 C&H- B2 P- B2

Appendix S: Pictures of the iced tea from the R-index test.
NOISE= C&H, UC= United Sugar (Cane), UB= United Sugar (Beet), P=Pioneer
B1= Batch 1, B2= Batch 2

NOISE UC- B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 P- B2 C&H- B2

NOISE UC- B1 UB- B1 C&H- B1 P- B1 UC- B2 UB- B2 P- B2 C&H- B2

Appendix T: Recruitment flyer for tetrad and hedonic rating study.

Sweetened Beverage Sensory Test

Would you like to take part in a sensory study? You are invited to participate in a sweetened beverage consumer test!

To be eligible to participate you must:

- Be available to participate in a 30-minute testing session on October 23, 28, 30 and November 4 and 6 OR October 24, 29, 31 and November 5 and 7
- Have no dietary restrictions or allergies
- Be willing to taste sweetened beverages

At the completion of the study you will receive **$25** for your time. Please e-mail Brittany Urbanus (Illinois.sensory.urbanus@gmail.com) for more information and to complete screening procedures.

hasslefreeclipart.com

Appendix U: Consent form for tetrad and hedonic rating study.

"CONSUMER ACCEPTANCE OF SWEETENED BEVERAGES"

You are invited to participate in a study involving sensory evaluation of "as is" sugar and sweetened Kool-Aid. The goal of this research is to determine consumer acceptance of the products tested in the study. The results of this study will be used to understand consumer acceptance of different sugar sources. The products will be evaluated using the tetrad test and the 9-point hedonic acceptance test. The tetrad test is a difference test used to determine if a significant difference is detected between the samples. You will be presented with four samples and instructed to sort them into two groups of two based on similarity. The 9-point hedonic test consists of a line scale with values ranging from 1 to 9 that measures your overall liking of a specific product. The lowest value (1) is associated with "dislike extremely" while the highest value (9) is associated with "like extremely". You will be asked to taste two samples independently and rate them in terms of overall liking.

There are no known allergens associated with the products tested. A complete list of ingredients is available for review. If you have food allergies or are diabetic you should not participate in this study. The University of Illinois does not provide medical or hospitalization insurance coverage for participants in this research study nor will the University of Illinois provide compensation for any injury sustained as a result of participation in this research study, except as required by law. You are free to withdraw from the study at any time for any reason and it will have no effect on your grades at, status at, or future relations with the University of Illinois. The experimenter(s) also reserve the right to terminate the participation of an individual subject at any time.

You will be participating in five, 30 minute session. Upon completion of the study, you will be compensated with $25. You are free to withdraw at any time during the course of the study. If you do not complete the study, you will be compensated for your time at a rate of $8/hour.

Your participation in this study is confidential. The researchers will keep the responses confidential, and any publications or presentations of the results of the research will only include information about group performance. Data gathered from the entire project will be summarized in the aggregate, excluding references to any individual responses. Photos of the panelists participating in this research may be taken and used in oral presentations, in order to give information about the experiment procedure. Names of panelists will not be associated with the photos. Panelists may opt for not having their photographs taken and this option will be included on the consent form. The aggregated results of our analysis will be for journal articles and conference presentations. Again, your input is very important to us and any information we receive from you will be kept secure and confidential.

You are encouraged to ask any questions about this study before, during, or after your participation. However, specific questions about the samples that could influence the outcome of the study will be deferred to the end of the experiment. Questions can be addressed to Dr. Soo-Yeun Lee (217-244-9435, soolee@illinois.edu) or Brittany Urbanus (847-772-2346, urbanus1@illinois.edu). You may also contact the IRB Office (217-333-2670, irb@illinois.edu) for any questions about the rights of research subjects. If you live outside the local calling area, you may also call collect.

I understand the above information and voluntarily consent to participate in the study described above.

- ☐ I have been offered a copy of this consent form.
- ☐ I am 18 years of age or older.
- ☐ I agree to have photographs taken of me while participating in this research.

Signature Date

____

Print Name

____

Appendix V: Exit questionnaire for tetrad and hedonic rating study.

1. **What is your gender?**
   - ☐ Male
   - ☐ Female

2. **How do you describe yourself? (check all that apply)**
   - ☐ American Indian or Alaska Native
   - ☐ Asian
   - ☐ Black or African American
   - ☐ Caucasian
   - ☐ Hispanic or Latino
   - ☐ Native Hawaiian or Other Pacific Islander
   - ☐ Other: ______________________________

3. **How old are you?**
   - ☐ Under 18 years old
   - ☐ 18-25 years old
   - ☐ 26-35 years old
   - ☐ 36-45 years old
   - ☐ 46-55 years old
   - ☐ 56-65 years old
   - ☐ Over 65 years old

4. **When purchasing sugar, what criteria are most important to you? Check all that apply.**
   - ☐ Brand
   - ☐ Price
   - ☐ Size of container
   - ☐ Sugar source
   - ☐ I do not purchase sugar

5. **Prior to this study, how would you respond if the ingredient list of a food item contained the following ingredient? Beet sugar**
   - ☐ Purchase a different brand
   - ☐ Purchase it less often
   - ☐ Continue to buy the same amount
   - ☐ Purchase it more often

6. **After completing this study, how would you respond if the ingredient list of a food item contained the following ingredient? Beet sugar**
   - ☐ Purchase a different brand
   - ☐ Purchase it less often
   - ☐ Continue to buy the same amount
   - ☐ Purchase it more often

Appendix V (Cont.)

7. **Evaluate the following statements**

I expect a product made with beet sugar to taste better than a product made with cane sugar.

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

I would prefer to buy beet sugar as opposed to cane sugar for home use in cooking and baking.

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

8. **Prior to this study, how would you respond if the ingredient list of a food item contained the following ingredient? Cane sugar**

- ☐ Purchase a different brand
- ☐ Purchase it less often
- ☐ Continue to buy the same amount
- ☐ Purchase it more often

9. **After completing this study, how would you respond if the ingredient list of a food item contained the following ingredient? Cane sugar**

- ☐ Purchase a different brand
- ☐ Purchase it less often
- ☐ Continue to buy the same amount
- ☐ Purchase it more often

10. **Evaluate the following statements**

I expect a product made with cane sugar to taste better than a product made with cane sugar.

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree

I would prefer to buy cane sugar as opposed to cane sugar for home use in cooking and baking.

Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree